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A CYBERNETICS OF CHAOS

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in

HISTORY OF CONSCIOUSNESS

by

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The dissertation of Ronald Bruce Eglash
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A Dissertation in History of Consciousness by Ron Eglash

Abstract

This dissertation is concerned with the cultural significance of the rise of mathematical models of chaos. The first half of this analysis attempts to demonstrate that while these models are indeed a more holistic alternative to previous information science theories, they are not ethically superior. I have tried to show that the cultural claim for an ethics of holism has developed in a mutual historical construction with the scientific claim for a cybernetics of holism. Along one axis we have the parallels between recursion in humanist theories of liberation, and recursion in technical theories of computation. Along the other we have the organicists' romantic depictions of more concrete, more natural communication, and the cyberneticists' pedantic systems for less discrete, more analogical representation.

The second half of this analysis makes use of these mathematical models in empirical studies of material culture and communication. This is carried out through measurements of acoustic waveforms -- in particular a comparison of the of Reggae and Rap as examples of analog/digital dichotomy -- and through a study of fractal structure in African art and architecture. Finally, this work shows that the history of cybernetics and chaos theory has been influenced by these ideas from the African diaspora, and that my research is not so much a discovery of fractal geometry in Africa as it is an understanding of the African geometry of fractals.

Acknowledgement

Whenever I have a problem in keeping my work coherent and well organized, there is usually someone around who cheerfully comments "Well, isn't that appropriate for a study of chaos?" Having driven this excuse into the ground myself, I no longer find it amusing. Despite my best efforts, chaos offers no refuge from hard work.

The technical theory and methods I sought were well represented at UCSC. The bridge between cybernetics and deconstruction had been long traveled by Donna Haraway, and I owe much of the synthesis throughout this essay to her influence. Ralph Abraham was an old hand at the recursive mathematics of chaos, and introduced me to his scientific commmunity. My technical application of chaos to communication studies was granted material and intellectual support by Ken Norris at Long Marine Lab. Cultural analysis was a new field for me, and I was fortunate in having Carolyn Clark introduce me to anthropology, and inspire my focus on fractals in African architecture.

I am indebted to Billie Harris for her friendship and aid in various academic maneuvers at History of Consciousness, Ken Marten for his acoustic engineering at Long Marine Lab, Jim Clifford for his skepticism, Pat Zavella for her help on labor issues, and Gottfried Mayer-Kress for his aid at the Computational Mathematics Lab. I have also received a great deal of help from other graduate students, particularly David Bain in Biology, Peter Broadwell in Mathematics, and Crystal Gray in History of Consciousness. I am also indebted to Thomas Avila, Kirby Bunas, Nancy Campbell, Vince Diaz, Joe Dumit, Paul Edwards, John Hartigan, Miranda Hays, Sharon Helsel, Matthew Kobee, Ron Record, Adolph Smith, Sandy Stone, Marita Sturken, and Tom Trout. Financial support was provided by the Board of Studies in History of Consciousness, the Institute for Intercultural Studies, and the Institute for Global Conflict and Cooperation.

DEDICATION: for Mom and Dad.

Chapter 1: A Deconstruction of Cybernetics

1.1 Introduction

In everyday life, chaos is a frequent companion -- we use this word to signify the disarray of an overused kitchen, the exuberance of a spirited party, or the snarl of afternoon traffic. But chaos can also be a signifier of signifiers, a comment on the disorder of a system of information. It is in this sense that chaos becomes not only of political concern, but an object of scientific inquiry as well. This essay will explore some of the recent innovations in the science of chaos, and discuss the ways in which our cultural conceptions of chaos have both created these innovations, and have been changed by them.

The title of this essay has both political and scientific meanings. The word "cybernetics" was coined by mathematician Norbert Wiener to refer to the interdisciplinary study of information systems; it is derived from the Greek word *kubernan:* to govern. The political meaning of chaos is frequently that of "anarchy" -- the absence of government. Thus the political translation of this title is "a governing of no-government," a phrase which, I hope, conveys a sense of the unavoidable paradox of such goals, as well as my occasional utopian optimism.

For the scientist a cybernetics of chaos is also somewhat paradoxical. How could a science of information systems, a study of order, be applied to disorder? Yet science, like politics, can give a utopian side to chaos. Indeed, we find that the two histories have many people and concepts in common: scientific study of natural and artificial systems has often been employed to prove or disprove the need for strong, centralized government, and political needs have often motivated the creation of scientific models in which a natural or necessary order is at question. Biological science is a classic example of this kind of connection. While Hobbes' *Leviathan* used the chaos of Nature as proof for the necessity of strong government, Kropotkin's *Mutual Aid* gave a formidable defense of

anarchism through its description of biological systems of cooperation and balance.

In current political/cultural theory there is often a decisive social division, either implied or directly stated, in which some characteristic of the chaotic is held responsible. All too often this is analyzed only in terms of a linear, organized oppressor and a holistic, chaotic oppressed; as if there were some innately liberatory characteristic in chaos. Butler (1988) for example reviews the use of psychoanalytic portraits of the unconscious mind in feminist theory: "Lacanian theorists insist upon the unconscious as a source of discontinuous and chaotic drives or significations... which contest the rigid and hierarchizing codes of sexual difference..." (p. 9). Here it is assumed that oppression is structured by order, and thus disorder is innately liberatory. Hartsock (1988) suggests that this sexist oppression through order parallels racist oppression; she paraphrases Memmi in *The Colonizer and the Colonized:* "the Others are not seen as fellow individual members of the human community, but rather as a part of a chaotic, disorganized, and anonymous collectivity" (p. 4). But by focusing on oppression through order, we overlook the ways in which hegemony is served by chaos, or liberation brought forth through linear organization. In racial sterotypes for example, the construction of the Primitive does indeed depend on notions of uncontrolled, disordered savages, but its counterpart of the Oriental disparages a supposed excess of order: lack of emotion or spontaneity, a mind that can only think of commerce, and mental abilities that are mystically abstract. Similar contradictions can be found for many other identities (sexual orientation, gender, physical ability, economic class, etc.).

Within either stereotype -- oppressed as too chaotic and oppressed as too ordered -- we might categorize two different liberatory moves: Sameness and Difference. The Sameness approach would deny the stereotype, attempting to show why those disparaged as chaotic are actually well ordered, or vice-versa. The Difference approach would confirm the stereotype but deny its import, attempting to show why being chaotic is just

as good as being ordered (or vice-versa). In both of these categories there is often an effort to make the case by objective, testable theories: a science of chaos is employed as the means of elucidating the particular attributes of the chaotic which are involved in this social division.

The move towards sameness requires that we play by the rules. In *The Savage Mind* Levi-Strauss opposes the sterotype of the intuitive, organic, irrational primitive by demonstrating that their symbolic systems are as physically arbitrary and internally logical as those of technological societies.* Within the science game claiming that order is better than chaos, Levi-Strauss plays and wins. But we don't get to contest the game itself, and the effort often seems a denial of one's own identity -- as if to say "we are your equal only in as much as we are like you."

The move towards difference is also problematic. Carol Gilligan's *In a Different Voice* argues against claims for superior male rationality by making use of psychological studies on "chaotic" thought -- relational, dynamic, emotional thinking -- to discuss the positive human attributes suppressed by linear, ordered cognition. In such instances, science is used to turn tables on the dominant duality; chaos changes from the inferior category to the superior one.

The problem with this approach is that it still leaves the dichotomy intact, and the dichotomy itself is in part a product of the domination being opposed. As Spivak (1988) says, it is "reversal without displacement." If we wish to argue that men have a psychological deficit because of their servitude to rationality and fear of chaos, we support the belief that men really are more rational and ordered. And since we know that this notion of the oppressed as more chaotic is sometimes an illusion created in support of domination, this valorization of chaos works against us. During the student political movements

*Levi-Strauss is not completely strict about this distinction when discussing the oral/literate dichotomy; Derrida (1976) takes him to task on this (see chapters 3 and 4 for further discussion).

of the 1960s for example, radical women were habitually told that their organic, nurturing essence made them best suited for work in kitchens and bedrooms. When leaders of the South African government claim that Blacks are closer to nature, more intuitive, and are better off "unspoiled" by modern mechanistic society, they are not making a liberatory gesture.

Thus in attempting to redeem chaos, to analyze and specify the liberatory characteristics it holds, we often find ourselves reinscribing the kinds of fixed power structures that we were trying to oppose. It may be a help here to consider, as in the first paragraph of this essay, the difference between chaos as signifying a description and chaos as a signifier of signifiers. The most important point of the characteristics of chaos is not that they are purely illusions created by a self-serving elite; nor is it that they demonstrate some mechanism of utopian transformation, or hold a universal tie to the Natural Good. Their significance lies in the fact that they have entered into the system of human meaning.

If we approach chaos from this perspective, then we find ourselves in a grey area between two major paradigms. On the one hand, we cannot simply accept the dominant assumption that the oppressed really are more chaotic; we know many specific instances where this is a carefully constructed lie, and revealing it as such goes a long way in liberatory struggles. On the other hand, we cannot simply accept the dominant assumption that the chaotic is really inferior; there are times when we would like to agree that the oppressed are doing things differently, because we see that different way as better. Each strategy offers a universalist, totalizing view; by itself an essentialist position.

> She is this Inappropriate/d Other who moves about with always at least two/four gestures: that of affirming "I am like you" while pointing insistently to the difference; and that of reminding "I am different" while unsettling every definition of otherness arrived at (Trinh 1986 pg 11).

Staying between these two extremes, unsettling the essentialism, calls for both a very specific analysis of chaos, and at the same time a very fluid one. Even the cornerstones of oppressed and oppressor need some flux: a theory which sees a totally evil, omnipotent enemy against a pure, powerless victim will erase the complexities that can be a source of resistance for the oppressed and self-critical insight for the oppressor.

In summary: We need to be able to show how chaos may be characterized, to detail its mechanisms and manifestations. But we also need to be open to the ways in which these characteristics may have very different meanings in different contexts: essentialist standpoints will not work.

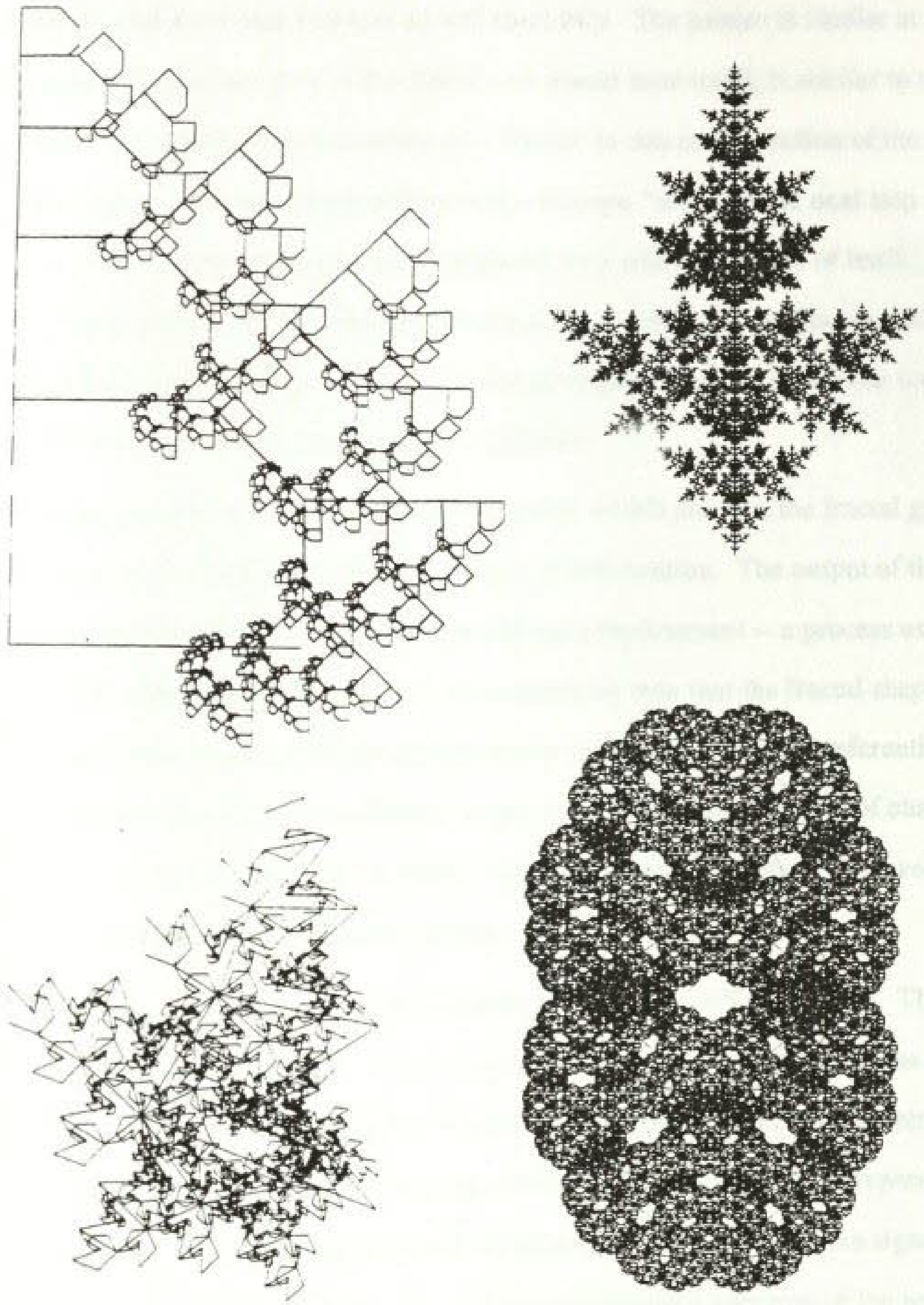
1.2 Two Characteristics of Chaos: A Cybernetic Interpretation

Throughout this essay we will be examining chaos in its normally rich variations of meaning, but we will focus on chaos as it is strictly defined by post-modern mathematics. It is in the play between these two definitions, their contradictions and parallels, that the thesis of this essay resides. This section will briefly introduce this mathematical definition, as well as my cybernetic interpretation of it. Historical elaboration will be provided in chapters two and three, and chapter four will make a detailed examination of this technical theory.

Current models of chaos include non-linear dynamics, cellular automata, ergodic theory and fractal geometry; this section will consider only the last. Figure 1.1 shows several examples of Benoit Mandelbrot's famous fractals. These computer generated images are based on theory which 19th century mathematicians thought irrelevant to physical reality. Mandelbrot (1982) has demonstrated that they are in fact an extremely common natural form.

> Scientists will (I am sure) be surprised and delighted to find that not a few shapes they had to call *grainy, hydralike, in between, pimply, pocky, ramified, seaweedy, strange, tangled, tortuous, wiggly, wispy, wrinkled,* and the like, can

Figure 1.1: Various fractals



Generated by the author using FractaSketch by Dynamic Software Inc.; dist. Aerial Press, Santa Cruz.

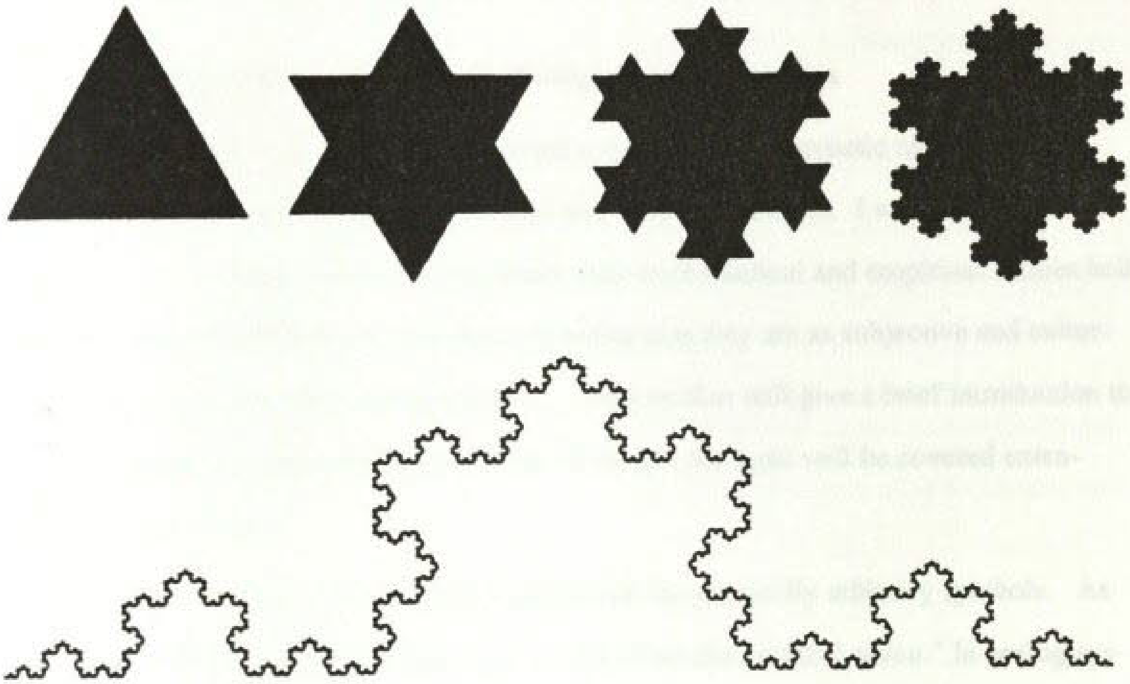
henceforth be approached in rigorous and vigorous quantitative fashion (pg 5).

Fractals exhibit the odd property of *self-similarity.* The pattern is similar at many different scales, so that any part of the fractal, no matter how small, is similar to the whole. Figure 1.2 shows the construction of a fractal, in this case a section of the Koch "snowflake" curve. The snowflake begins with a triangle "seed", in the next step the mid-section of each side of the triangle is replaced by a smaller version of itself. This process is repeated down to whatever minimum scale is involved: in this case down to the resolution of the printer; in the case of a real snowflake down to molecular ice crystals; and in the case of mathematics down to infinity.

The mathematical or computational description of this process, the fractal generation algorithm, has a circular or "recursive" flow of information. The output of the replacement operation becomes the input for the next replacement -- a process usually created by self-referential programs. It is not surprising then that the fractal shape, the "signal" in ink which is generated by this recursive algorithm, has a self-referential physical structure (self-similarity). Recursion is one of the two characteristics of chaos we will consider. It is an integral part of chaos, both for mathematical models as well as the real chaotic structures they attempt to emulate.

Almost any system which represents information can be self-referential. This sentence, for example, refers to itself. But the recursive information in the previous sentence is represented by physically arbitrary symbols; we can't *see* the self-reference in this signal. If I have a fractal generation algorithm print out only numbers representing screen coordinates, then I will again be unable to see any self-reference: the signal is a series of physically arbitrary symbols, not the chaotic physical structure of the image. The chaos generated by self-reference can be represented either by a signal which has a correspondingly chaotic physical structure, or by a signal which has an arbitrary physical structure. I will refer to all representation by arbitrary physical symbols as *digital*

Figure 1.2: Koch "snowflake" generation



representation, and that in which the physical structure of the signal reflects the information it transmits as *analog representation*. This duality of analog and digital representation constitutes the second characteristic of chaos that we will consider.

In summary: Post-modern mathematics suggests that chaos is generated by self-reference. Both analog and digital systems can represent this information.

1.3 Two Characteristics of Chaos: A Biological Interpretation

Throughout this essay I will be making a case for my cybernetic model of chaos, claiming that it is verified by mathematical and empirical studies. I will also be deconstructing such sciences, disrupting the claim that mathematical and empirical studies hold special powers of verification, and demonstrating that they are as subjective and culturally embedded as any other social practice. This section will give a brief introduction to the undisrupted, scientific verification side of things; the topic will be covered extensively in chapter three.

In digital systems information is represented by physically arbitrary symbols. As Bateson (1972) said, "there is nothing sevenish about the numeral seven." In analog systems information is represented by a proportionality between changes in physical parameters of the signal and the changes in information. Loudness in human speech is a good example of analog representation. As I get more excited, I often speak louder: the physical parameter changes in proportion to the change in meaning. But we are always monitoring our own loudness, regulating it according to feedback: it is a recursive system. And because this is an analog representation of the recursion, it has a physically recursive signal: loudness (at least in English speech) is a fractal.

Evidence for the fractal geometry of loudness is given in Voss and Clarke (1978). They also show that pitch variation in music -- which I would categorize as primarily analog -- is a fractal, and that the pitch variation in the linguistic portion of English

speech -- which I would categorize as primarily digital -- is not. In addition they show that music with more vocals tends to be less fractal. Thus systems which are neither purely digital or analog will have signals with a "fractalness" that reflects this combination.

In chapter 4 I will return to examine this in detail; for now I want to comment on the possibilities. I have so far presented only acoustics, but any behavior can be seen as a signal -- writing, body movement, facial expression, neural firing -- indeed, any material expression of information. If we know that such a system has some kind of recursion, we can use this as a aid in determining whether it is analog or digital (or somewhere in-between). If we know something about a system in terms of analog/digital difference, then we can use this to as an aid to investigating recursion.

In summary: a strong claim for this cybernetics of chaos would contend that it provides an objective method for differentiating between analog versus digital systems, and recursive versus non-recursive systems.

1.4 Two Characteristics of Chaos: A Cultural Interpretation

The analog/digital dualism is closely related to a wide variety of other dichotomies: gestalt/analytic, holism/reductionism, concrete/abstract, and intuitive/logical are but a few. The politics of these dualities are highly charged -- the notion, for example, that a holistic viewpoint is inherently more ethical than a reductionistic one. If I claim an objective method for discriminating between analog and digital, and apply it to a political theory that says that one is morally superior to the other, then I claim an objective method for discriminating between good and evil -- not only a reversal of my anti-authoritarian goals, but (even to many who do not share these goals) a moral absurdity.

The concept of recursion or self-reference also finds a wide variety of cultural isomorphisms: the concept of self-governed societies, worker self-management, student-run

education, self-help psychotherapy, etc.. Obviously these too are highly charged political constructs, and a claim to an objective basis for defining them would, within their political theory, be an objective method for defining liberation -- once again a defeat of my desires and sensibilities.

My attempt to escape from these absurdities will be by two routes. One is through the cybernetics itself: to show that any significant portion of human culture -- speech will be the main example -- cannot be categorized in terms of the analog/digital dualism because it will always have too many different communication channels, each with its own analog/digital characteristics, and each interwoven with the others in a complex and varying whole. This dynamic multidimensionality will place similar restrictions on the determination of recursion. The issue will be taken up in detail in chapter four.

The second route is by way of postmodern cultural critique, which insists that neither recursion versus non-recursion nor analog versus digital has any inherent tie to liberation. Recursion or self-reference has had little critical reflection in much of its history of incorporation into liberation theories, particularly in the humanist tradition -- "increasing the control people have over their own lives" -- as well as in some radical traditions such as Marxism. Critical theory studies, recently invigorated by the work of Michel Foucault,* have countered with subtle explorations of power/knowledge discourse, explications of the formative and shaping, rather than merely repressive aspects of power, and genealogies of our institutional "regime of truth" (particularly in the construction of the subject). Such studies undermine the popular rhetoric of "self-control" and reveal its dark side of self-exploitation. For example, in contrast to the

*Feminist and anti-colonial discourse have folded postmodern critiques back on themselves, asking about the social context in which these meta-theories arise -- a practice which not only redefines meta-theory, but also contests the absence of acknowledged contributions by such oppositional knowledges to the origins of post-modern studies (cf work by Trinh and Hartsock). This issue will be taken up in chapter 3.

notion of "humanizing" prisons by helping prisoners create their own goals and guidance, Foucault (1977) quotes Servan on the founding of prison reform in 1767:

> A stupid despot may constrain his slaves with iron chains; but a true politician binds them even more strongly by the chain of their own ideas; it is at the stable point of reason that he secures the end of his chain; this link is all the stronger in that we do not know of what it is made and we believe it to be our own work; despair and time eat away the bonds of iron and steel, but they are powerless against the habitual union of ideas, they can only tighten it still more; and on the soft fibers of the brain is founded the unshakable base of the soundest of Empires.

A naive humanist sees political self-reference only as freedom; a critical theory extremist sees it only as subtle enslavement. Throughout this essay we will examine different instances of recursive cultural processes in light of cybernetics, and will examine the cultural construction of cybernetics in terms of this cultural recursion.

Theories about the inherently liberating characteristics of analog systems are usually within the Romanticist or organicist tradition. Here a story is told of the fall from orality to literacy, from natural ecological dynamics to a calculating world of artifice, from original analog innocence to the sin of digital modernity. But postmodern theorists, primarily deconstructionists, have demonstrated that these stories of purity and wholeness are tightly bound to repressive (and often repressed) agendas: the construction of "primitives" living in childlike grace (and thus in need of the parental guidance of colonialism), the enforcement of one authentic version of Women's Culture (excluding those interested in math or similar symbol systems as "male-identified"), and other totalizing theories in which analog plays the role of natural or Real, the authentic, uncoded, Good.

Against these organicist constructs, deconstructionists have "reversed and displaced" the binary polarities, developing such portraits as that of a deeply coded orality in the "primitive" (eg Derrida 1976) and the possibilities of feminist liberation in digital technology (eg Haraway 1985). Throughout this essay I will be following this deconstructionist path, pointing to the presence of digital systems where we are told there is

only analog, examining the ways in which these systems of arbitrary symbols can be deeply intertwined with liberatory struggle, and citing instances where analog dynamics are a repressive, dominating force.

Since deconstruction has many of its roots in literary analysis, and since these texts are of arbitrary symbols, it has been particularly adept at pointing to the ways in which digital systems can be fluid, complex, and embrace the strange depth of human experience. But for this reason deconstructionist analysis persistently omits the possibilities of analog representation. The Romantic tends to see life as full of authentic, non-represented events; the deconstructionist tends to see only representation by arbitrary symbols. While I agree with deconstructionists in the need to see systems of representation, I do not find that representation is restricted to arbitrary symbols, and the way this restriction operates in the cultural sphere creates some dangerous omissions. As in the case of cybernetic recursion, this synthesis between cybernetic representation and deconstruction will be taken up explicitly in the following chapters.

This essay is not simply a list of struggles and their unfairly denigrated information systems. Yet to say more than that, to claim that I know which kind of information systems should be used in different circumstances, opens the door to claims of a single, perfect liberation theory, the kind of monolithic authority I wish to oppose. What is needed is some method of allowing these systems a more egalitarian co-existence; an opening of the space in which power is joined to knowledge. My claim is that this system of systems can also be approached in terms of cybernetics.

But cybernetics itself is not an innocent, abstract entity which hands out objective pronouncements. It is a social construction, a set of cultural practices with its own history and objects and personalities. There is no way for me to use cybernetics as a political tool without analyzing the politics of cybernetics; to see how this tool is bound in the webs of social relations and cultural practice. This becomes a bit tricky; how can I use

cybernetics to make statements about the world if, at the same time, I am deconstructing cybernetics, contesting its claims to absolute truth and opposing its bids for power? But the question assumes that cybernetics is a single cohesive force, a one-way street with obedient drivers. The following sections will show that this is far from accurate; the street is full of jay-walkers, skateboards and back alley ways, and it is in this fuller map that one finds room for political maneuvers.

1.5 Cybernetics: An Origin Story

Social studies of science and technology have not always been concerned with cultural context. Traweek (1982, 1988) divides the history of science studies into three stages. The first stage begins with nineteenth century epics on the heroic quest for knowledge, and ends with Karl Popper's positivist dream of the progressive accumulation of truth through rational, universal and self-evident criteria for evidence and theories. In the second stage the social matrix previously ignored as "external" to science began to emerge as an important factor in the structure of scientific process. Traweek notes that this began during the political emergence of the "third world," with its cross-cultural perspective on industrialization, and was later invigorated by the war in Vietnam, the ecology movement and other social concerns. The seminal work of this stage is Kuhn's 1962 description of relativistic paradigms in which science frames its theories and labor. In our present third stage of "cultural studies," research has started to focus on detailed explication of the cultural construction of these paradigms, and current interpretations range from slight modifications of Popper's positivism (science as empirical rationality with a bit of cultural impurity stuck to its surface) to Feyerabend's view of science as elite anarchic theatrics. The paradoxical conflict between the asocial universality of science, as evidenced by its success in physical manipulations and predictions of the world, and the social particularity of science convincingly evidenced by these cultural

studies remains at issue.

In the conclusion of this text, I will review some of the current approaches to science studies, and try to compare the results of this work to their various theoretical stances. For now, Traweek's own research will provide illustrations of the strengths and weaknesses of this cultural science studies approach. In her excellent ethnography of the particle physics community, she enters into the local symbolic structure and describes how ethnicity, sexuality and other "external" factors are intimately wound into the electromagnetic coils and bubble chambers of physics institutions. She circumvents some of the universality/particularity paradox by showing how universality itself is manipulated as a social symbol among the physicists. The choice of postdoctoral students, for example, is described by the senior physicists as an extraction from a small percentage of the population who are unaffected by culture; the process is explained (and no doubt envisioned) by the physicist as isomorphic to the extraction of signals from noise in the particle detectors. This status of aculturality is signified by certain behaviors in regard to sexuality and social norms. My favorite (Traweek 1982, pg 49) is her description of the graduate student who habitually shoved huge amounts of bread into his mouth at restaurants. Rather than censure the student for poor etiquette (as would be the case in Literature or History, where social graces are academically required), the senior physicists delightedly told waiters to "bring this fellow some more bread;" the violation of social law being a good sign of preoccupation with the laws of physics.

I find Traweek's study more problematic at moments when her reading of this cultural text starts to transcend the locally produced codes and rely on standard universalized theories, particularly Freudian sexual symbols (pg 273). When she suggests that the acronyms of the labs SPEAR and PEP are connected with phallic imagery I am not particularly sceptical, but to also suggest that the lab SLAC has an associated gynic imagery leaves me perplexed: have the predominantly male researchers at SLAC acquired a

feminine outlook, or express an extremely well hidden bisexuality? A similar problem occurs in her reading of the particle detectors. They are described as "apparently passive" devices which "are rather more like a trap set to snare elusive signals" -- a gynic invocation -- and she notes that one detector with the acronym of LASS has lip-shaped magnetic coils which make it easy "to grasp the labial associations in the detector's name." Yet she also posits the particle signals as female and the scientist's detection as male, and often seems to summarize with the standard "man is to woman as culture is to nature" conclusion. A code of universal masculinity -- the "Platonic rejection of flux" -- is forced onto a system which may have a very different symbolic structure.

Traweek's work has thus been both an inspiration and caution for my own investigation into cybernetics. It provides a model for how scientific universality can be incorporated into a description of science as cultural process, and warns against the use of universalized theory for this cultural interpretation. As a strategy for avoiding such universalized perspectives, I will be using cybernetic theory to investigate the cultural history of cybernetics.

This recursive strategy of turning a theory back on itself is typical among postmodern theorists. Derrida, for example, uses Rousseau's theory of language development to critique Rousseau. Clifford (1988) describes the cultural context of anthropologists, and derives a recursive inquiry from this ethnography of ethnography. Psychological critiques of Freud, showing his theories to be the result of neurotic drives, and marxist critiques of Marx, demonstrating the ways in which his concentration on the powers of the free market economy glorifies capitalism, would both be examples of a self-referential approach. The best example from the sciences is Gödel's incompleteness theorem, a mathematical proof of the incompleteness of all systems of mathematics.

There are several advantages to recursive critiques; they are a way of demanding a certain kind of integrity -- "if your theory is so good for everyone else, you should be

able to apply it to yourself." It can be used to beat someone at their own game in systems we don't like, and sharpen self-criticism in systems we favor. The self-reference often seems to create a second perspective, as if the system was "jumping out of itself" (see Hofstadter 1979 for an excellent exploration of this phenomena in science, art, and daily life).

There are also disadvantages to recursive analysis. The circularity often makes it a bit difficult to follow. In the case of cybernetics, itself a science of recursion, there are moments when it seems like the circularity escalates into ever-rising levels of confusion. How can recursion add a second perspective if it was already part of the first? Does cybernetics have some sort of epistemological imperialism we can never escape from? Perhaps the opposite it true; it may be that all recursive systems contain their own potential self-destruction.

The grab-bag of sciences centered around "information" -- theory of computation, communication theory, systems analysis, etc. - have their origins in equally diverse sources, ranging from pure mathematics to pragmatic engineering. Steven Heims' *John von Neumann and Norbert Wiener* grounds the evolution of the information sciences, particularly that of cybernetics, in a comparison of the personalities and practices of these two founding scientists. Wiener and von Neumann (see figure 1.3) not only played instrumental roles in the birth of this new science, but came to symbolize the nexus of technical and social oppositions which cybernetics drew around the themes of chaos and order. Wiener's chaotic systems were both recursive and analog: dynamic signal flows linked through feedback loops, or larger self-organizing networks based on statistical relations in random process. In these flexible, decentralized systems Wiener saw models for political self-determination and local autonomy -- and perhaps a bit of himself as well. His orderly opposite, von Neumann, worked only with digital systems: manipulations of arbitrary symbols by logical operations on hierarchical sets of rules. Recursion

Figure 1.3: Norbert Wiener and John von Neumann

Norbert Wiener demonstrating analog device to translate speech sounds tactile sensations for the deaf. Wiener's work centered around the information embedded in physical dynamics, and following WWII was focused on humanitarian projects.

John von Neumann poses in front of the digital computer he developed for the calcualtions needed to construct the first nuclear weapons. After WWII he continued to work on military systems which operated by manipulating physically arbitrary symbols.

was rarely used, and then only to introduce exact repetition. The static hierarchy of von Neumann's systems paralleled his political leanings toward a centralized, elite government, as well as some facets of his own personality.

While this dualistic sketch makes a clear, strong case for the cultural embeddedness of science, it is dangerous in that it seems to confirm a totalizing or essentialist position: chaos as inherently liberating and order as inherently oppressive. Although Heims does not explicitly write against this kind of determinism, his text is well suited for a more complex view; the history is presented as "that of the Cubist painter who paints on one canvas many views of a face whose various facets may differ in shape, content, texture, and color, but nevertheless complement each other in elaborating a central, complex reality" (pg xiii). I will perform some reassemblage of these parts, both to problematize the seemingly obvious duality, as well as to emphasize the themes I will be using throughout my own text.

Norbert Wiener's upbringing (b. 1894) combined the awkwardness of a child prodigy with an ignorance of his Jewish origin; by age 15 he came to recognize that he was outside both the American social mainstream and the community of his heritage. His father, a Tolstoyan who had come to the U.S. with the intention of starting a utopian community, applied harsh educational methods to his son. Norbert later expressed his ambivalent feelings over this in a metaphor to the work of a sculptor: "Let those who choose to carve a human soul to their own measure be sure they have a worthy image after which to carve it, and let them know that the power of molding an emerging intellect is a power of death as well as life."

John von Neumann (b. 1903) grew up in the same middle class Budapest which produced Dennis Gabor, Eugene Wigner, Leo Szilard, and Edward Teller. This "Hungarian phenomenon" of scientific fertility has been analyzed by various science historians; Heims emphasizes the explanation of the scientists themselves, summarized by Gabor as

"Innovate or die." For von Neumann, the precarious existence of a wealthy Jewish banking family underscored this philosophy. The Neumann family's upwardly mobile past, their flight from the brief communist government of 1919, and the scapegoating of Jews by both left and right resulted in a conservative, cosmopolitan outlook, one which was reinforced by the elitism of the German universities he later attended. Unlike Wiener's outsider identity, von Neumann's intellectualism was a part of the social skills which allowed him to maintain the status he desired.

These differences in personal philosophy were echoed by the differences in scientific approach. Von Neumann's mathematical and technological productions always involved a logical system of absolute control and hierarchical abstractions. Wiener's style of thinking, as well as its products, reflect a much greater ambivalence over control -- his work was usually in terms of physical process and sensory experience, including a deep involvement with the chaotic aspects of the physical world.

Von Neumann's first major success was his work in the late 1920s on the mathematics of sub-atomic particles. At that time, there were two very different descriptions of the sub-atomic world. Schrodinger had described a physical process model in which the particles were like vibrating waves, the various octaves of each wave corresponding to the possible energy states of the particle. Heisenberg's alternate description was based on a matrix representation for the position and momentum of the particles. Von Neumann found a method of combining the two models into a single abstract formalism, creating a logical system of axioms and theorems which provided a mathematical language of quantum mechanics.

Wiener was also influenced by mathematical logic, but had far less invested in its approach. At the age of ten, he wrote a paper titled "The Theory of Ignorance" which attempted a "philosophical demonstration of the incompleteness of all knowledge." Although he did much of his early work within the frame of analytic philosophy and

symbolic logic, he stuck to his original conviction. Von Neumann also had early contact with the theories of formal structure, but he believed it would be possible to prove all mathematics to be complete and free of contradiction, and joined in the attempts to carry out this proof.

In 1931 Kurt Gödel produced a proof which demonstrated conclusively that for any formal system there are propositions which are true and yet cannot be deduced by the formal system. All formal systems are incomplete. Von Neumann pronounced this a "catastrophe;" Wiener took it as a reassuring comfort.

While von Neumann had jumped into the mainstream competition of quantum theory, attempting to construct a formal system which could reflect the ultimate order of matter, Wiener became involved in a somewhat esoteric study of disorder. It had been known since the invention of the microscope that tiny particles suspended in water bounced around erratically. This "Brownian motion" is due to the bombardment of the particle by molecules of the water; a schematic of the path taken by such a particle is given in figure 1.4.

The intriguing aspect of this path is that its chaotic nature does not change as we look at smaller and smaller scales. A single move in this path (the distance from one dot to the next) might be as much as a half inch, or only a quarter inch, or an eighth, a six-teenth.... There is no limit. This means that any tangent drawn to this "curve" will have a different slope depending on the scale; there is no way to define a derivative (rate of change) for this shape, it is "undifferentiable."

Such undifferentiable functions had been mathematically described in the late nineteenth century, but were quickly disregarded as unimportant anomalies. As Saks (1937) noted, researches dealing with undifferentiable functions "were regarded almost as the propagation of anarchy and chaos where past generations had sought order and

harmony." Wiener's approach was quite the opposite; he wanted to begin with chaos and allow his mathematics to emerge from there.

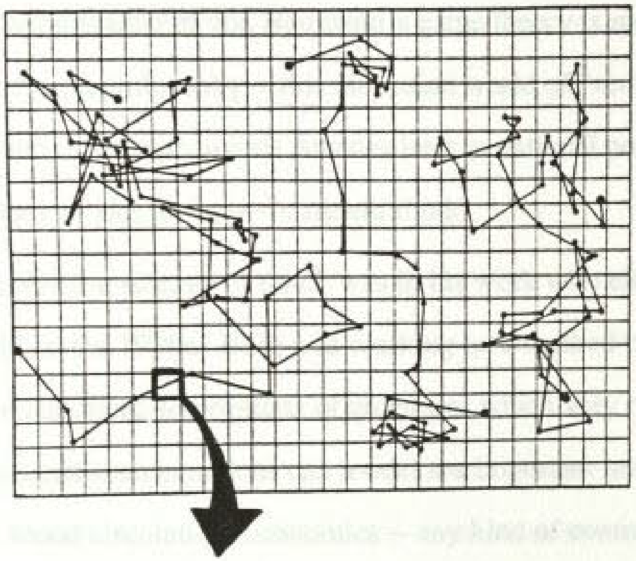
> The moods of the river were always delightful to watch.... At one time the waves ran high, flecked with patches of foam, while at another they were barely noticeable ripples. Sometimes the lengths of the waves were to be measured in inches, and again they might be many yards long. What descriptive language could I use that would portray these clearly visible facts without involving me in the inextricable complexity of a complete description of the water surface? This problem of waves was clearly one for averaging and statistics.... Thus I came to see that the mathematical tool for which I was seeking was one suitable to the description of nature, and I grew ever more aware that it was within nature itself that I must seek the language and the problems of my mathematical investigations (quoted in Heims pp 68-69).

The contrast between von Neumann's formalization of sub-atomic waves and Wiener's more holistic approach to the river waves provides an excellent illustration of their differences. Wiener's pleasurable involvement with his senses, and his acceptance of solutions which avoid "complete description," find their complement in von Neumann's insensible sub-atomic world and attempts to construct a formal system which would capture all essence.

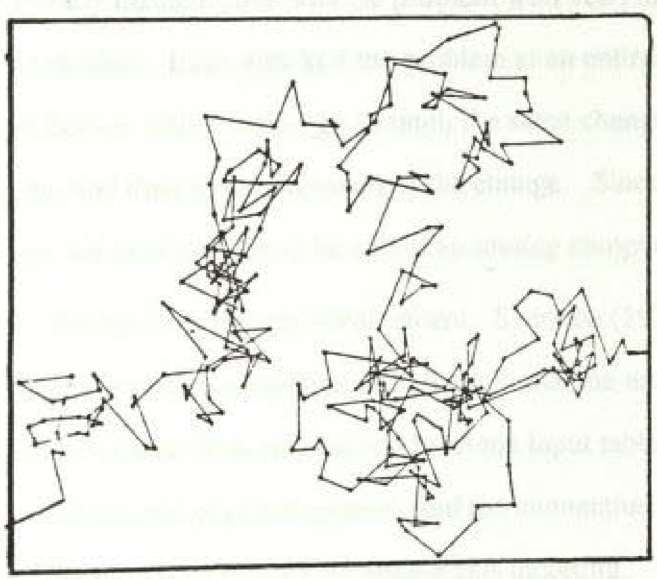
This difference appears throughout their work. Both worked on weather prediction for example, but von Neumann attempted to solve differential equations giving exact expressions of abstract atmospheric models, while Wiener looked at statistical properties of real weather systems. This contrast in their approaches to knowledge, always significant, became an issue of life and death when they began to seek a knowledge of knowledge.

Von Neumann's first investigation of mental activity was in game theory. This was a matter of representing all the "relevant" aspects of the game in symbolic terms and then calculating outcomes by mathematical proofs. For example, in many two-person games one player's loss is the other's gain; this becomes a specific class of games termed "zero-sum." The game is further reduced to specific moves or strategies (eg bluff, bet

Figure 1.4: Scaling in brownian motion



Observations of brownian motion



Irregularity occurring between observations

low, etc.), and then outcomes are calculated for every possible combination. The 'mental activity' here is in one sense trivial; the model simply assumes that each player is acting only in their self-interest and asks if there is a way to calculate which strategy will maximize winnings. The significance of von Neumann's game theory is more the question of its reflection on his personal philosophy -- this Hobbsian world of "zero-sum" and calculating self-interest -- and its reverse impact decades later in national policy, the mathematics becoming a model for how we *should* think.

Wiener's start towards a science of mind was in his work with electrical engineer Vannevar Bush at MIT in the 1920s. Bush was working on a method of solving differential equations, the mathematical descriptions of quantities which vary continuously through time. The systems such equations can model are important and quite common -- weather, traffic flow, blood circulation, economics -- any kind of continuous changes in time or space might be described by a differential equation. But finding the solutions to these equations is extremely difficult; this was the problem with von Neumann's approach to weather prediction. Bush attacked the problem at an entirely different angle, constructing a physical device which would go through the same changes as the system he wanted to investigate, and then simply measuring the change. Since the "computation" occurs by analogy, the device came to be called an *analog* computer.

From the start this device had military involvement. Shannon (1938) for example, notes that it was "in connection with a problem in ballistics" that the analog computer's ability to generate functions rather than rely on cumbersome input tables was discovered. Both the familiarity with dynamic physical systems and the connection to ballistics must have been reasons for Wiener's WWII work on antiaircraft targeting.

The main targeting problem was in taking the difference between the present aim of the gun and the radar-sensed position of the target, the "error signal," and using that information to reposition the gun. This problem of *feedback* is similar to driving a car

down the road; if you have an error, say a bump that knocks you toward the side, you can note (quickly) the distance between the center of the lane, where you should be, and your present position, where you shouldn't be, and try to steer back to center (the *setpoint* of the system). A poor driver will often overshoot the setpoint, and try again, possibly to overshoot once more -- hence the "weaving" of drunk drivers. Such oscillations might get smaller and finally stop; since the feedback is negating itself these damped oscillations are called *negative feedback,* a quality of stable systems (which antiaircraft guns obviously must be). Negative feedback allows a system to correct its errors, always returning to the setpoint. Unstable systems, drunks who overshoot more and more each time, are termed *positive feedback.*

The notion of feedback as a common method of "error correction" in living systems, particularly that of the motor system, inspired Wiener and others to begin a systematic interdisciplinary study of information systems.

Von Neumann also became involved in this interdisciplinary research as a result of his wartime efforts. His work on the construction of an atomic bomb had also led to a need for solving differential equations, which he approached through numerical computation using digital computers. During that time he became interested in attempts to create formal models of information processing in neurons, and the possibilities of improving digital computer design based on these models.

In 1945 Wiener contacted von Neumann, and the two organized a small meeting at the Princeton Institute to discuss some of the common ground between engineering and biology. The following year, under sponsorship of the Macy foundation, a philanthropic medical organization, they helped to organize an interdisciplinary conference of scholars from a variety of fields to encourage the development of this new area of study. Originally titled "Conference for Circular Causal and Feedback Mechanisms in Biological and Social Systems," the participants agreed, at Wiener's request, to use his newly coined

term, "cybernetics."

> Until recently, there was no existing word for this complex of ideas, and in order to embrace the whole field by a single term, I felt constrained to invent one. Hence "Cybernetics," which I derived from the Greek word *kubernetes*, or "steersman," the same Greek word from which we eventually derive our word "governor" (Wiener 1950 pg 23).

Although he continued to attend what eventually became semiannual conferences, von Neumann was dissatisfied from the start with the direction that cybernetics was taking. In a letter to Wiener, he states that the problems "reside in the exceptional complexity of the nervous system, and indeed of any nervous system" (Heims pg 204). He proposed the bacteriophage as an alternative subject of study, since the new techniques in microscopy allowed these organisms to be examined "in the exacting sense in which one may want to understand a detailed drawing of a machine -- i.e. finding out where every individual nut and bolt is located, etc.."

Military involvement became the force which, in their final years, drove the two apart. Wiener became a public figure through his adamant opposition to the military, and concentrated his technological efforts towards medical applications. He presented a cybernetic critique against both communism and capitalism on the basis that neither allowed a truly "self-governing" society, and contrasted them to the "homeostasis" of local community control. Von Neumann, meanwhile, spearheaded efforts to increase the development of nuclear arms. He complained that studies of radiation effects were too strict in their concept of human tolerance, and encouraged an immediate nuclear attack against the USSR.

1.6 Judeo-Cybernetic Tradition

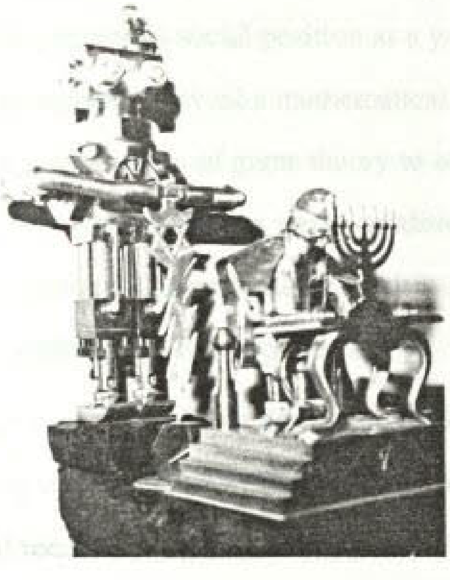
Heims, a physicist, is primarily concerned with the role of the scientist in society, and the possibilities of raising the consciousness of the scientific community. He marks out three main features of Wiener's life as fundamental to the formation of his

political/technological outlook. The most obvious is his father's Tolstoyan influence, as reflected by Wiener's anarchist leanings and interest in mathematical models of self-governing systems. Another is his social awkwardness, particularly as a child, emphasized by his myopia and physical clumsiness. Heims suggests that this created "a profoundly sensed need to impose discipline, that is, order, on himself," thus giving a psychological basis to his work on the mathematics of chaos. The third is Wiener's identity as a Jew.

Heims notes two different ways in which Wiener's Jewishness entered his thinking. One is simply the tradition of seeing everything, including science, as part of a moral universe. The second is from Wiener's text *God & Golem, Inc.*. A golem, in Jewish legend, is a clay figure which, under the proper circumstances, can become animated by placing a tablet inscribed with the name of god into its mouth. It was usually created to protect Jews in times of persecution, although it could be used for labor as well. Goldsmith (1981) reports golem legends going back to the fourth century B.C.E., and describes their continuing popularity in twentieth-century literature, film, theater and other media (see figure 1.5). Most golem legends concern the moral question of humans taking over a task that belongs to God. Since the golem is primarily a physical being it is overtaken by physical desires -- often sexual -- and eventually goes out of control, causing chaotic destruction and requiring its own demise (usually by pulling The Name out of its mouth).

In *God and Golem, Inc.* Wiener makes an analogy between cybernetic machines and the robot-like golem. The golem was created to save the Jewish community from destruction, but became a danger; modern technology also has the potential to destroy its creator. The ironic title can be read as Wiener's search for a method of combining moral guidance with modern science -- to incorporate God and Golem. Heims suggests that Wiener's ambivalence over his father's sculpting of his youth, creating him in a chosen

Figure 1.5: Some modern incarnations of the golem



"The Rabbi and the Golem" -- metal sculpture by Harry Friedman of Oak Park. Photo courtesy of Arnold Goldsmith.

"Superman meets the Galatic Golem." Superman is a registered trademark of DC Comics Inc; illustration copyright 1972 DC Comics.

Actor David Gans in *Black Golem*, American Twist Productions. Photo by Frederick Sweet, copied from Goldsmith (1981) pg 26.

image, was reflected in this caution against the hubris of technological creations.

Heims' profile of von Neumann emphasizes his upper class Hungarian Jewish background as the crucial element in his personality. He repeatedly points out how the disorder of this precarious social position as a youth was reflected in von Neumann's adult efforts to impose or reveal a mathematical order in various aspects of the world. In von Neumann's application of game theory to social science, for example, Heims writes that his "Hobbesian" assumptions were "conditioned by the harsh political realities of his Hungarian existence." His enthusiasm for the use of nuclear weapons against the Soviet Union is also attributed to this experience.

Although I am primarily in agreement with Heims' analysis here, I would like to expand on it in some points. Obviously these kinds of studies always present a danger of psychological reductionism, of carelessly reading a work as if it was the biography of the author. But even putting such questions of evidence and representation aside, there are some issues in which my analysis fundamentally differs. Most problematic for me is the notion that Wiener was trying to battle against chaos inside himself, and to reduce chaos to order in the world at large. There is some truth to this, but it sounds far too much like von Neumann. I think Heims is more on target when he quotes Wiener's colleague Armand Siegel: "Wiener, when he talked about 'chaos,' which he loved to do, was very close to talking about the psychic and instinctual chaos inside himself, which both scared and intrigued him all his life" (pg 154).

When I think about my own youth, I find that Wiener and I have much in common. Like Wiener, I grew up both socially and athletically awkward, becoming increasingly aware of my Jewishness but remaining outside of its formal tradition. We both had fathers whose anarchist leanings came out of Jewish experience, and mothers whose Southern upbringings involved a break with Jewish tradition. And while I can recall an urge to defeat the identity of chaotic misfit -- as a child, for example, I was constantly

attempting to comb the curly tangles of my hair into the straight symmetries of my gentile peers -- I also recall great joy in that identity, a feeling that chaos was a legitimate and positive place to be in. In what ways did Wiener have a positive sense of chaos, and how did it relate to his own Jewish identity?

I see this affirmative side of chaos in a great deal of Wiener's technological work, particularly in his use of statistical randomness as a way of gaining information about what he saw as an essentially indeterminant world. Heims contrasts this to von Neumann's formal system view: "Whereas Wiener viewed random process, chaos, as fundamental, von Neumann saw mechanisms and logics underlying all scientific phenomena." Wiener extends this when making a comparison between the statistical physics view and the psychological view of Freud: "This recognition of an element of incomplete determinism, almost irrationality in the world, is in a certain way parallel to Freud's admission of a deep irrational component in human conduct and thought" (Wiener 1954 pg 19).

Like Wiener, though not as extreme, Freud gained only a gradual awareness of his Jewish heritage. In the preface to *Totem and Taboo,* he noted that the new edition was being published for the first time in Hebrew, and writes that although he had no formal Jewish upbringing, he nevertheless felt that his personality was somehow fundamentally Jewish. In an extensive investigation of Jewish influence on Freud's thinking, Baken (1958) suggests that this was an overstatement of Freud's distance from Jewish learning, motivated by his concern over too close an association between psychoanalysis and Judaism. But he concludes that it was precisely this conflict between the formal Jewish tradition and its non-formal aspects that Freud was most concerned with. He quotes from Freud's B'nai B'rith Lodge speech on his seventieth birthday:

> But there remained enough other things to make the attraction of Judaism and Jews irresistible -- many dark emotional forces, all the more potent for being so hard to group into words, as well as the clear consciousness of our inner

identity, the intimacy that comes from the same psychic structure (pg 305). Freud must have been pondering the status of his non-formal Jewishness in terms of his psychological theory of knowledge: if formal Jewish tradition is a primarily conscious expression, then its non-formal aspects would be closer to the subconscious realm. I am interested in how that same question worked in terms of Wiener's cybernetic theory of knowledge, and its contrast to that of von Neumann's.

There are some obvious links between the idea of "formal" Jewish tradition and the "formal system" in which von Neumann modeled all of his problems. Action determined according to a set of explicit rules, knowledge encoded in systems of physically arbitrary symbols, an ultimate order controlling apparently chaotic phenomena -- these are themes throughout formal Jewish theology as well as the principles by which von Neumann modeled the world.

As Aronson puts it in *The Jewish Way of Life,* "The Jew does not face the world of nature with fear and trembling. It is not a world of chaos, but one moving by divine laws." So too for the world of society. Just as the pograms of Eastern Europe inspired centuries of intensive textual study for Jews seeking to find an order to the painful chaos of their existence, von Neumann's game theory system reflected a logic which could combat the disordered experience of his Jewish Hungarian youth. His technological masterpiece, the digital computer, can be viewed as an extension of Talmudic scholarship; it provides a tool for the exhaustive analysis of symbol strings which are thought to hold the secrete of existence.

It may seem odd to portray von Neumann, an agnostic according to his friends, as so involved in Jewish tradition. But this is quite in keeping with his upbringing as a traditionalist. Anti-semitism was not as extreme in America, and the growing numbers of Jewish scientists allowed him to include this identity as a part of upper class, Old World

charm.* Heims writes that he was quite at ease with his Jewish origins, and continued to use Yiddish in joking with his many Jewish friends, some of whom were religiously devout.** For von Neumann the digital models, with their claims to universal truth, may have filled this religious space in his identity: "His brother observed that John von Neumann's preoccupation with the models seemed to lead him to experience feelings akin to awe, if not religious feeling" (Heims pg 325).

Von Neumann's ease with Jewish language and custom, his tie between traditional Jewish encodings of knowledge in symbol and formal rules and his own digital encodings of the world contrast greatly with Wiener's Jewish identity, as well as with his technological approach. Just as Wiener's analog devices operated on physical structure, rather than the physically arbitrary symbols of von Neumann's digital devices, so Wiener's discovery of his Jewish heritage was deeply involved in his own physical structure:

> When I became aware of my Jewish origin, I was shocked.... I looked in the mirror and there was no mistake: the bulging myopic eyes, the slightly averted nostrils, the dark, wavy hair, the thick lips. They were all there. (Wiener, quoted in Heims pg 15)

I suspect that there are many elements of ethnic identity -- voice intonation, gesture, eating habits, walk, etc. -- which are primarily analog representations, embedding information more in physical dynamics than as physically arbitrary symbols. In my personal recollections these were crucial to the formation of my own Jewish identity; I think they were important to Wiener's as well. If this is so, then the contrast between Wiener's analog technology and von Neumann's digital technology are in striking parallel to the differences in their identities as Jews.

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*Traweek notes that this association between Jewish ethnicity and scientific identity still continues in the particle physics community, where she was told that one should "behave British and think Yiddish, but not the other way around" (pg 171).

**See Plotnikov and Silverman (1978) on occasional Yiddish as a system of Jewish ethnic signaling.

I began this section by asking what the relationship was between Wiener's view of the possibilities of chaos as a positive force, a source of information rather than a mere negation of knowledge, and his sense of himself as a Jew. Assuming the previous characterization to be true, the question can be rephrased: How did Wiener's identity as an "analog Jew" help to create his advocacy of chaos?

As I pointed out at the beginning of this essay, there is no inherent reason for claiming that chaos is more closely tied to analog representation than to digital representation; such claims come from cultural views, and not from any property intrinsic to analog systems. Thus the previous question will be approached by looking for sources in Jewish culture which tie analog representation to chaos. In addition I noted that self-reference *does* have chaos as one of its intrinsic properties. This suggests that while looking for sources in Jewish culture which tie analog representation to chaos, the search will be aided by looking for information which flows in circular loops, feeding back into itself. The next section will describe how both of these features can be seen in Jewish conceptualizations of gender; and it is in gender and sexuality that both von Neumann and Wiener delivered their strongest message.

1.7 Gender, God and Golem

The clearest description of the mapping between gender divisions and this analog/digital division in Jewish culture is in the work of Jewish feminists. Adler's 1973 essay, "The Jew Who Wasn't There," presents a classic position for Jewish feminists. She begins by noting the connection between women's peripheral status in Jewish culture and the division between women's association with *gashmiut* (physicality) and men's association with *ruhniut* (spirituality).

Adler writes that within the traditional formal religious system, both gender restrictions and positive religious commandments for women ensured that "A whole woman's

life revolved around physical objects and physical experiences -- cooking, cleaning, childbearing, meeting the physical needs of children." Men's commitments were primarily concerning the formal systems of text (Torah and Talmud) and Jewish law *(halakhah);* systems made up of physically arbitrary symbols.

This division between women's non-formal sphere of physical process and men's sphere of formal symbol systems is a close parallel to the analog/digital dichotomy, and thus to an important difference between Wiener and von Neumann. Returning to Heims again:

> Many of Wiener's mathematical articles... make frequent reference to physical processes. His use of apparently visual (and possibly tactile) images derived from the apparatus or phenomena of physics offers another insight into his preference for mathematics related to empirics.... By contrast, visual or geometric visualization seemed not to play an important role in von Neumann's thinking (pg 128).

Von Neumann's thinking is described as "operating sequentially by purely formal deductions... [on] a collection of symbols." The irrelevance of physical process to his thinking contributed to the success of his computer design: "Von Neumann was first person who understood explicitly that a computer essentially performed logical functions, and that the electrical aspects were ancillary" (pg 182).

Just as von Neumann found physical process irrelevant to his cybernetic knowledge, there is a strong male Jewish tradition which tends to find physical process irrelevant to spiritual knowledge. Here only the formal systems of physically arbitrary symbols have a direct relation to God. Thus the dualism becomes not merely analog versus digital, but analog versus spiritual -- gashmiut versus ruhniut. As Adler points out, this isolation from the spiritual allows the physical realm -- and by extension women -- to take on dangerous possibilities.

> In the Jewish view, all physical objects and experiences are capable of being infused with spiritual purpose; yet it is equally true that the physical, unredeemed by spiritual use, is a threat. It is therefore easy to see how women

came to be regarded as semidemonic in both Talmud and Kabbalah (pg 16).

While under external control, this female physicallity can be spiritually redeemed, but it is always in danger of becoming self-controlled -- in this case a chaotic self-reference: "The Talmudic sages viewed the female mind as frivolous and the female sexual appetite as insatiable. Unless strictly guarded and given plenty of busywork, all women were potential adulteresses." Here female physicality is a positive feedback loop, insatiably generating its own disorder. But as Foucault has pointed out in his studies (albeit not in these terms), self-referential loops are not just sources of individual self-motivation. They can also be used as methods of institutional control. Adler describes this in the stories of *tzadeket,* model women whose masochistic self-sacrifice -- starving herself, selling her hair, bathing in ice water -- were to be emulated. "Implicit is the assumption that virtue is to be achieved by rejecting and punishing the hated body.... [This is] the self-annihilating model of the postbiblical *tzadeket*" (pp 15,17). The tzadeket acted as the setpoint to a negative feedback loop, a self-negating system which opposed any deviation from its norm.

For Adler the realm of gashmiut is one of defeat --it is either a source of evil disorder, isolated from the spiritual, or one of self-negating subservience to someone else's spirituality. For her the only solution is to end the isolation of women in gashmiut by including them fully in the formal system. She proposes that this occur only through the traditional system for alterations in *halakhah,* the formal law, thus making the changes in women's status entirely within the currently defined codes.

Adler concludes her essay by making an analogy between Jewish women's status as physical laborer, limited in access to spirit, and another physically-bound worker: the golem.

> For too many centuries, the Jewish woman has been a golem, created by Jewish society. She cooked and bore and did her master's will, and when her tasks

> were done, the Divine Name was removed from her mouth. It is time for the golem to demand a soul (pg 17).

In talmudic commentary a woman who has not conceived is sometimes referred to as a golem -- a being whose physicallity threatens uncontrolled danger. Just as the legendary golem was only given spirit by its limited textual contact, a contact by which its subservience was maintained, Adler sees Jewish women trapped into their labor roles by restricted access to the formal textual system. By increasing access to the digital, God and golem are incorporated.*

Waskow (1983) provides a quite different view of Jewish feminism, one which makes use of analog representation. Just as Wiener saw physical structure as representing cybernetic information in his analog devices, Waskow sees the traditional physicality of Jewish women's culture as a legitimate place to develop spiritual knowledge and status.

> We can enrich the Jewish sense that the spirit *is* the body, that the spiritual and the physical fuse, by encouraging dance, mime, body movement, breathing, the arts and artisanship, and the theatrical "acting" as a part of prayer, Torah study, and midrashic storytelling. Already this process is being renewed by many women and some men (pg 268).

Waskow describes the ways in which physical patterns within both nature and culture pervade Judaism, and the possibilities for a feminist renewal of Judaism by increasing their epistemological and spiritual status. Here the physical is not passive. It's dynamical changes are seen as a complex and powerful representation of knowledge, both natural and artificial. Not only can we see Wiener's liberating use of analog representation in this conception, but the chaos of nature, the uncontrollability of self-

*I would be remiss if I did not mention Ozick's imaginative reworking of the golem story in modern New York. Here the Jewish lawgiver is a woman (a lawyer) who accidentally makes a female golem out of some potted plant soil. The traditional narrative structure is faithfully retained -- with the exception that this golem has excellent literary skills -- and her accelerating sexuality does in several men before The Name is snatched from her mouth. See also Marge Piercy's *He, She, It*.

governing systems, is also presented in a positive light: "The birth of a new person is the biological archetype of freedom in the historical-political arena. Every birth brings newness, uncontrollability, into the world" (pg 263). By increasing access to the analog, God and Golem are incorporated.

Before complicating this picture further, I want to consider the dangerously erroneous conclusion we might come to if we stop at this point. If we simply write off Adler as being "male-identified" (i.e. a digital sell-out), then it is possible to interpret this in terms of a standard organic-feminist holism: Wiener achieved his humanitarian political outlook because his Jewish identity came from the analog, female aspects of Judaism, from the natural harmonies of the chaotic pagan Godess, who was killed by the digital artifice of patriarchy. But this essentialist answer would do injustice to both Jewish feminism, as well as to Wiener. Indeed, this reasoning has been repeatedly cited by Jewish feminists as a source of anti-semitism within the women's movement:

> The old Christian charge of Deicide, that the Jews murdered God incarnate in the ultimate masculine body form of Jesus Christ -- rejected in recent times by many denominations -- is now being resurrected by some revolutionary feminists in different form: the accusation that the Hebrew people were responsible for the destruction of the ultimate feminine deity, the Godess (Daum 1982).

Waskow (1983) is Arthur Waskow; the fact that he is male is not incidental. Among Jewish feminists his analog advocacy is in the minority; it is his position, and not Adler's, which is more commonly seen as a sell-out. The notion that women are more in touch with nature and therefore more spiritual has been used, again and again, as a rationalization for keeping Jewish women out of the formal system -- since women are "naturally spiritual," they have less need for formal practice. Hazleton (1983) has analyzed the ways in which this naturalized femininity has kept many Israeli women in constricted social roles: "The 'real women' myth... gives them an insidious pat on the shoulder, together with the time-worn line, 'Man's biological function is to do, woman's is to be.'"

Even for those Jewish feminists who do take the holism-Goddess route, there may be a more positive view of digital coding than in the usual organic feminism. In her essay on Jewish lesbian-feminism, Bauman (1983) begins with the standard story of holistic, healing goddess-centered cultures replaced by patriarchy. But she adds that the ancient Hebrews have been unfairly singled out because they "were one of the very few groups to carefully codify this." In Bauman's organicism, codes and laws are not an inherent cause of alienation or evil.

The idea that traditional Jewish women were truly isolated in gashmiut, physicallity, is also contested by feminists. Hyman (1975) provides an historical study which indicates that traditionally Jewish women were heavily involved in a highly coded economic system, requiring textual and numeric skills as well as emotional control and a shrewd head for business. Many other writers weave digital systems into their feminist works: Deborah as a judge in ancient Israel, a great-grandmother who loved to read Torah, the Marrano women who became formal religious leaders, the texts of Jewish women's fiction -- all disrupt the common sterotype of female/male as physical/symbolic.

This contestation of the mapping between female/male and analog/digital changes the answer to questions of Wiener's identity. If we ask about the reality of this mapping -- are women in Jewish culture really more involved with analog systems -- we will never be able to give an answer; there are numerous strands of analog mixed in with strands of digital in almost every human endeavor (a view I will give mathematical and empirical support to in chapter 4). But we *can* make definite statements about the *claims* a culture makes about itself. Female/male may not "really" be strongly divided by analog/digital, but there really is a sterotype that divides them in this way. And for this reason I think it reasonable to see all three dualisms -- Wiener/von Neumann, analog/digital, and female/male -- as linked together through Jewish culture.

The affinity of Jewish women for digital systems -- despite whatever displacement this may involve -- adds some additional restraints to an analog identity. For one thing, it means an openness to the possibilities of digital representation -- certainly a characteristic of Wiener, but not surprising considering the overwhelming influence of mathematical symbolics in the sciences. More meaningful is the implication for analog systems as a form of representation. When Jewish feminists do take on the idea of finding spiritual knowledge in the physical realm, it is in direct comparison to the way that digital systems hold spiritual knowledge. The result is a sense of analog systems as representation -- artificial, malleable, self-reflexive. To see them otherwise is to leave women with a passive spirituality: "Man's biological function is to do, woman's is to be" -- a gender inequality Wiener writes against in his autobiography. And it was in this sense of active analog representation, of information encoded in physical dynamics, that Wiener did his best work.

This is not to say that Wiener never lapsed into the passive identity of a biological essentialist position. In his first autobiography he relates a discussion with J.B.S. Haldane in which they considered the possibility that the higher fertility in Jewish scholars as compared to "the western christian learned man" could have "tended to breed in... whatever hereditary qualities make for learning" (pg 12). But this racism is directly opposed by Wiener in the bulk of the text. He explains that the discovery of his Jewish ancestry created a dilemma: If he denied his Jewishness he would only continue the anti-semitism which had hidden it from him, but he felt that his outsider position made impossible a "flight into Abraham's bosom." His solution was to identify himself as Jew by his commitment to resistance against all prejudice, for "in resisting prejudice against the Oriental, prejudice against the Catholic, prejudice against the immigrant, and prejudice against the Negro, I felt that I had a sound basis on which to resist prejudice against the Jew as well" (pg 155).

In these comments on his Jewish identity Wiener flips between the two safety zones of biological essentialism and abstract pan-cultural identification; he seems reluctant to play in the dangerous area of the subliminal, informal and illegitimate. But the subject frequently arises in casual observations throughout his books. And here it seemed to me that these remembered early contacts with Jewish culture -- the "gefullte-fish atmosphere" of his New York relatives, his cousin Olga's faith in Judaism, his grandmother's "Jewish family structure" -- were primarily through women. It was his grandmother who provided the earliest recollection, and while he is quite specific about the ways in which the physical dynamics of her voice and gesture rooted her origins from the Old Country, these roots had other aspects as well:

> She read her own newspaper, printed in a foreign typeface which I later found out to be Yiddish.

Recap: I began this history of cybernetics with a caution. A strong case can be made for the ways in which the duality of Wiener and von Neumann link chaos versus order, in the technical side of cybernetics, with freedom versus totalitarianism in the social side of cybernetics. Yet I am opposed to essentialist linkages; for the reasons I have outlined in the first section, we cannot accept an inherent, innate, deterministic freedom in either chaos or order. By closely examining both the characteristics of chaos in cybernetics, and the cultural context in which these conceptions arise, the essentialist, universalist appearance gives way to located complexity and contradiction. Wiener's opposition to sexism, racism, and economic and political subjugation may well have been sparked by his identification with women, but it was also a part of his identification as a Jew. His analog approach is associated with his Jewishness, but only as a part of the chaotic, physical realm, outside formal Judaism. Jewish feminists may identify with the chaotic, analog realm, but typically these are male Jewish feminists. Male Jewish feminists may reverse the traditional status of symbolic (digital) over physical (analog), but the

existence of these categories as distinct, separate areas is only a claim that the culture makes about itself; the reality behind this dual signification is a multidimensional web intertwining wide ranges of both analog and digital throughout the cultural terrain.

1.8 John von Neumann: The Cybernetics of Sex and Death

While Wiener provided us with a close look at his personality through his autobiography, von Neumann's interior life was much more hidden. In this section I will return to Heims as a source of insight into von Neumann's thinking.

Jewish views on physicallity as a source of uncontrolled danger are isomorphic with von Neumann's problematic relation to bodies. They were best dealt with at a safe distance -- "upon entering an office where a pretty secretary was working, von Neumann habitually would bend way over, more or less trying to look up her dress" -- or not at all: "Johnny was entirely unathletic and could not do anything physical, he noted. I knew that von Neumann delt with this limitation by cultivating a fine contempt for athletics." At times Wiener seems much more at ease with his body despite his physical disabilities:

> One can imagine Wiener at MIT, walking the long, industrial halls, leaning backward in his ducklike fashion, looking up as he tossed peanuts into the air and caught them in his mouth -- a skill he had perfected (Heims pg 381).

Von Neumann's most potent comment on bodies and gender was his work on a formal model for the bacteriophage. This microworld, like his game theory microworld, offered a formal system of exact specifications -- in this case the specifications for reproduction. While Wiener worked on analog devices such as artificial arms, devices which were based on physical dynamics and incomplete information, von Neumann worked on a theory of self-reproducing automata, digital machines which could replicate themselves exactly.

Such machines would be free of the chaos inherent in beings which reproduce by flesh and blood. Heims quotes von Neumann in a letter to George Gamow, who was then

working on a theory for metabolic construction of proteins by random interactions: "I shudder at the thought that highly efficient purposive organizational elements, like the protein, should originate in a random process." If von Neumann had a need for reproduction in human society, it must have conflicted with the chaos of the reproducers: orderly, self-reproducing automata could provide the resolution of this conflict.

As in my analysis of Wiener, I want to pause a moment to consider an erroneous conclusion. It is possible to read this as a very standard story on the evils of digital systems -- to claim that nature is analog, and that von Neumann's digital thinking produced his objectification of nature, including a view of people as objects, leading to his callous militarism and sexism. But as I stated at the beginning of this essay, the essentialist view positing an *inherent* tie between analog versus digital and good versus bad. is wrong. The source of these linkages are local, historical, and interpretative. In the case of Wiener I presented a counter argument starting with culture and moving to technology; here I will be going from technology to culture.

The idea of masculine desire for reproduction without bodies is a classic theme in theories of gender psychology. The concept is based on biological universals, and suggests a deterministic repression -- since men can't have babies, they are compelled to reproduce their physically alienated ideas. This is not necessarily an oppositional, feminist critique however -- Plato proudly asserts this hierarchy of reproduction as the escape from mundane flux into spiritual order, and it seems to be a fairly common notion in modern pop psychology. For example, in Turkle's (1984) ethnographic study of computer programmers, an MIT hacker explains the predominance of males in computer science:

> Men can't have babies, and so they go have them on the machine. Women don't need the computer, they have them the other way. Why do you think people call their ideas brainchildren? (pg 235)

The ways in which modern technology is able to ignore the physical world adds additional weight to this womb envy scenario, and several theorists have incorporated this into social analyses of science. I have already mentioned Traweek's description of particle physics in terms of "the imaging of scientists as male and nature as female, with detectors as the site of their coupling." Sofoulis (1988) uses a combination of science and science-fiction to describe the ways in which "libidinal energies" are "displaced from body to machines," including both space flight ("upward displacement") and machine intelligence ("resurrecting dead matter"). Edwards (1985) suggests that the characteristics of military information technology -- robotics, artificial intelligence, etc. -- are specifically coded masculine, and uses this to link militarism with the historical subordination of women.

Both Edwards and Sofoulis write that they are opposed to essentialist interpretations, emphasizing that this masculine psychology is only culturally coded onto these characteristics, but the coincidence between the cultural meanings and biological functions makes this opposition to essentialism difficult.* Cohen's (1987) study of intellectuals working in defense technology provides some excellent examples of non-coincident codings. Ironically, she began her research, a detailed participant-observation study at MIT, with some essentialist expectations -- eg the phallic significance of missiles. But Cohen found that this expectation was frequently contradicted in her research: domestic or even maternal metaphors for nuclear weapons were quite common. Like Traweek, Cohen manages to incorporate such reversals within the psychoanalytic narrative, but she concludes that the symbolic system is much to complex for a reductive analysis.

Considering the ease with which Turkle's hacker used womb envy to justify the exclusion of women in computer science, and the contradictions one finds within

*Actually Sofoulis presents a psychoanalytic analysis much too complex for such a simple assessment; by the end of her argument the lines separating biology and culture are quite blurred.

empirical studies, Cohen's call for a "more complex analysis" is compelling. What is needed is not the essentialist determination of male versus female sexuality with specific symbols or characteristics, but the details of how these associations are strategically manipulated. How can we predict, or at least understand, the *adaptive* dynamics that allow gender signs -- female and male -- to be redistributed among the symbols and characteristics -- soft and hard, digital and analog, chaos and order, referential and self-referential -- which link them to social power structures? What is it that maintains the stability of power relationships during these changes?

My own goal in this mapping is not, I admit, a particularly deep examination into theories of gender psychology. I am simply attempting to use specific examples from the history of cybernetics to illustrate the ways in which technological codings of sexuality are not innate, but rather result from local cultural contexts. In the case of von Neumann, I would maintain that although his own use of self-reproducing automata is consistent with an essentialist framework -- a claim that digital representation and recursive replication are inherently tied to a repressive masculinity -- the main precursors to his work did not show this relationship.

The theoretical basis for von Neumann's self-reproducing automata depended on two prior developments; a digital system capable of self-reference, and machine intelligence based on such systems. Together all three can be viewed as evolutionary links in a continuous recursive chain: in the first stage a system in which information can fold back on itself, in the second stage a system which can fold back information *about* itself, and third a system in which its self-representation can fold back into its own replication. Despite this cybernetic continuity, the personalities of the people who developed the concepts for the first two systems contrast strongly with that of the third.

The story of Ada Lovelace is now well known in computing science history. Her fame stems from her writings in 1843 on the mathematical possibilities of Charles

Babbage's proposed "Analytical Engine" -- a plan for a digital computer. Since these writings include a recursive program (the "first stage" of my evolutionary typography leading to von Neumann's digital reproducers), Lovelace has been given a legendary position as the first software engineer. Her legacy is curiously flexible. On the one hand, Lovelace is promoted as a recovered feminist ancestor; a position which tends to over-estimate her achievements and obscure her own thinking. On the other hand, she has been appropriated by the military -- "Ada" is a computer language developed specifically for the defense industry -- and her presense in computer science texts often serves liberal discourse on the equal opportunities provided under capitalism. Against these reductive portraits, Stein (1985) has written a detailed, critical examination of Lovelace which reveals a much more interesting and complex story than the popularizations have allowed.

Lovelace's mother was always worried that she might have inherited the notorious sexual proclivities of her father, Lord Byron. Her childhood revolved around strictly prescribed educational activities, and at times she was forced to lie perfectly still with bags over her hands to ward off any "wildness." The forced rests contributed to the chronic ill health she would experience throughout her life.

This repressed upbringing eventually inspired rebellion in the form of an attempted elopement, but the failed affair left her humiliated and repentant. She wrote to a family friend, William King, requesting mathematical instruction as a cure for her sinful impulses.

King agreed, sending her both mathematical and religious texts. But despite her declarations to apply her mathematical imagination "to the greater glory of God," she turned away from the moralizing of King to the more glamorous social company of Babbage and his famous "thinking machines." Babbage's motivations were far from King's religious intellectualism. He was primarily concerned with economic and scientific

progress; his calculating engines were both modeled on and designed for the division of labor as proposed by Adam Smith in *The Wealth of Nations*.

This switch from King to Babbage was an act of independence, and Lovelace began to turn her imagination loose. While having a much more intense area of mathematical study, her religious thinking also took an expanded turn. She began to describe herself and her work in terms of magical imagery: the mechanisms of symbol manipulation were "mathematical sprites," and Babbage was advised to allow himself to be "unresistingly bewitched" by "the High Priestess of Baggage's Engine." Taking advantage of his sometimes careless attitude toward theoretical explanations of his device, she settled on the title of Fairy, insisting that she would be the guiding order to Babbage's work. The pragmatic Babbage protested against this fantasy, but was finally forced to give himself "wholly up to Fairy-Guidance."

This identity of math-fairy symbolizes the mixture of forces Lovelace attempted to negotiate. Stein's evaluation is quite critical, and stems from her own background in the technical aspects of mathematics, computing and experimental practice, as well as her knowledge of the harsh conflicts facing women in science. Stein's study of the correspondence between Lovelace and her tutors demonstrates a surprisingly weak ability in basic symbol manipulation; she concludes that the fairy magic was not simply charm and imagination, but covered for this lack of digital competence. The mysticism was encouraged by Lovelace's mother, who did not want her daughter to have an independent career, and fostered a self-delusion about her abilities which prevented her from making the kind of assessments that learning requires.

Stein also notes that it was actually Babbage who first drew up the "table of steps" constituting the first computer programs. Babbage was having difficulty obtaining funding for his work however, and realized that Lovelace's social position and notoriety -- both as the daughter of Byron as well as a "Lady of Mathematics" -- could be put to his

advantage. The reputation of Lovelace as the originator of programming stems from this public relations ploy of Babbage. There was, however, one table for which Ada was wholly responsible: a recursive* program for calculating a sequence known as the Bernoulli numbers. Significantly, this was the one program which Babbage claimed credit for.

> We discussed various illustrations that might be introduced: I suggested several, but the selection was entirely her own. So also was the algebraic working out of the different problems, except, indeed, that relating to the numbers of Bernouilli [sic], which I had offered to do to save Lady Lovelace the trouble (quoted in Stein pg 89).

If von Neumann's self-replicating system was inspired by his envy of women's biological recursion, then it might well have a parallel in Babbage's appropriation of Lovelace's recursive achievement. This appropriation may have been anticipated by Lovelace: Stein notes that in the letters concerning this program Lovelace is atypically vague -- she had always been over-dependent on Babbage for mathematical specifics -- and speculates that the vagueness was deliberate. But in this story of male womb envy and the protective mother it is the digital non-body, not analog embodiment, over which the struggle is fought.

Indeed, Stein critiques Lovelace for being too "detached from the physical embodiment" of the device; her speculations on the possibilities of general symbolic manipulation were unrealistic considering the ways in which the fundamental structure of the machine used numeric relationships. Yet von Neumann's success with the electronic digital computer was attributed to exactly the same disregard of physical structure ("the

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*Moore (1977) states that this table used recursive programming. Huskey and Huskey (1984), apparently referring to this claim, suggest that this is a confusion with Lovelace's description of mathematical "recurrence groups," and note that the term "recursive programming" generally refers to a procedure which calls itself -- impossible for Lovelace since her code had no procedures. But they also note that she introduced a new code notation to describe "a cycle of a cycle" (Lovelace), which would be equivalent to the "recursive nesting" of programming structures in use today.

first person who understood... that the electrical aspects were ancillary"). Scientific success, as Stein is well aware, does not simply consist of digital competence; it includes an elaborate system of craft labor, business acumen, social prowess, and intellectual stratagems. All of these are tied into gendered social relations, and through them the position of scientist itself is gendered male (and similarly marked by race, class and other identities).*

Like many other Jewish feminists, Stein will have no part in analogical mystifications when the real knowledge and power lie in digital systems: "Unable to assimilate the symbolic processes with which alone highly complex and abstract matters may be rigorously treated, [Lovelace] remained vulnerable to mystical leaps and flights..." (pg 84). I disagree with this universalized privileging of digital representation, but Stein is quite right in terms of the local context. Perhaps if Lovelace had not been so distracted by her additional studies in music -- a highly complex and abstract matter, but harmlessly centered in analog representation -- she might have made more significant progress in her scientific work. Stein's description of Lovelace's differently abled acquaintance, Harriet Martineau, provides an interesting contrast in this regard:

> The deafness that developed in her early teens, largely depriving her of the pleasures of music, fed her habit of voracious reading. Much reading, as frequently happens, led to writing.... In due course, at one point or another, she championed the abolition of slavery, female suffrage, socialism, religious free-thinking, and mesmerism.

Unlike Martineau, Lovelace remained swaddled in privilege. and oblivious to the pains of the external world -- certainly not traits we would wish to cite as feminist ancestry (however much they may be). Stein provides convincing evidence, for example, that

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*Stein's description of Michael Faraday illustrates this point in terms of economic status. While his working class origins contributed to his exceptional abilities as an experimentalist, Faraday was "the last important physical scientist" able to boast that he knew no math. This too was a legacy of his lowly origins, and these educational barriers to lower class men were often changed only at the expense of upper class women.

Lovelace's famous philosophical statement on the inability of computers to produce creative thought was not so much an admirable exercise in cognitive studies as it was reassurance about job security to the upperclass.

Yet Lovelace also used her mathematics to rebel against attempts to limit her to proper femininity. Particularly interesting is her later interest in biology and medicine. Since her health problems were linked to the periods of enforced inactivity in her youth, this attempt resonates with practical and theoretical concerns of control over women's bodies in modern feminism. But even here her struggles were not simply organic redemptions: her plan was to duplicate the mathematical studies of electrical circuits, then in its infancy, on what she believed was the flow of "animal magnetism" in biological tissue. Perhaps she made some connection between the occult associations of this "magnetic fluid" and the pagan heritage from which her fairy identity originated -- fairys, after all, are creatures of order and guidance as well as nature and spirit. The fairy mathemagic which trapped her in fantasy and femininity also had a potent, rebellious side; but either way Ada Lovelace was not John von Neumann.

Unlike Lovelace's invention of recursive software, many people could be considered "inventors" of the idea of artificial beings -- none of them really original, and none of them yet successfully implemented. But it was Alan Turing's contributions which have come to define both the mathematics and psychology of artificial intelligence (the "second stage" in my cybernetic typography) for the last three decades. And for Turing, like Lovelace, these self-referential digital systems were a move away from the kind of repressive masculine identity that von Neumann lived. Indeed, Turing too was a math-fairy of sorts: his biographer, Andrew Hodges, has shown that Turing's closeted homosexual life combined with his brilliant intellectual achievements to produce a career hovering between austere logic and mathematical fantasy.

Like Gödel, Turing was interested in proving that all complex mathematical systems were incomplete, containing at least one unsolvable problem. Rather than develop a universal numeric system, as Gödel had done, Turing (1936) proved unsolvability by an abstract universal machine, one which could manipulate symbols according to any specifiable algorithm -- in other words, it could imitate any possible machine. These "Turing machines" could even represent their own description; it was by this self-reference that an unsolvable paradox was implemented. But it was also this meta-mathematics of a universal machine that provided the mathematical proof for the possible universality of a real digital computer. In his biography of Turing Hodges (1983) quotes from a letter by one of von Neumann's coworkers in digital computer design:

> Von Neumann was well aware of the fundamental importance of Turing's paper of 1936.... he firmly emphasized to me, and to others I am sure, that the fundamental conception is owing to Turing -- insofar as not anticipated by Babbage, Lovelace and others (pg 304).

If one day artificial intelligence (AI) arrives to the digital computer, it will hold its mathematical basis in the work of Turing. But more importantly, Turing has also provided a psychological definition for AI: the Turing Test. In his classic paper titled "Computing Machinery and Intelligence," he set out to provide an operational definition of intelligence. He began by describing a game in which a man and a woman are behind a door, and answer questions from an interrogator by written replies. The interrogator is to determine which is the man and which the woman; they are to attempt to deceive him in their answers. Turing then suggested replacing one person with an AI machine; the Turing test holds that if the interrogator cannot distinguish person from machine, then you have created true machine intelligence.

The examples of interrogator-machine dialogues in the paper use questions ranging from common sense to academic expertise. Since the interrogator can be anyone -- and as today's automatic voice machines and other human simulations increase, it frequently

is anyone -- the Turing test takes on a profound social significance. Rather than limit intelligence tests to a particular task or behavior (eg chess playing), the Turing test opens the question of mind into the human community.* And the idea may have been generated by Turing's desire for a more open community: he lived most of his life struggling to establish his identity as a homosexual in a homophobic society.

Both the Turing machine's ability to imitate other machines and this game of cognitive imitation echo the social experience of gays who live in a community where they must pretend to be someone they are not. And to some extent, the endless self-reference of meta-mathematics was Turing's hiding place from the anti-gay world surrounding him. But the sexual guessing game on which the Turing test was based worked against such normative gender restrictions: it suggested gender as something more fluid, less fixed -- a feature which recent computer systems have started to demonstrate. Van Gelder (1985) has described how communications over computing networks has occasionally inspired "on-line transsexualism," people whose electronic identities have a different gender from their own. Haraway (1985) has offered a number of imaginative examples in which cybernetic technology, including that of AI, has blurred and opened gender boundaries.

Mathematics had a double meaning for Turing. It was both a von Neumann-like emotional shield, a world of unhuman abstractions and endless self-reference, as well as an opening into consciousness and community. In the end this desire for opening killed Turing: during a robbery investigation he admitted his homosexuality to police detectives, and was arrested and forced to submit to hormone treatments. This eventually drove him to suicide. It was a tragic fairy-tale ending: he killed himself by eating an an

*Although Edwards (1988) points out that the Turing test emerges from a modern tradition of behaviorist repression-through-mechanization, Gray (1988) has written suggestively of the Turing test's radical potential in the postmodern context of subversive simulation and blurred boundaries.

apple dipped in poison. Hodges writes about this death in terms of the double meaning mathematics had in his life.

> Lonely consciousness of self-consciousness was at the center of his ideas. But that self-consciousness went beyond Gödelian self-reference, abstract mind turning upon its abstract self. There was in his life a mathematical serpent, biting its own tail forever, but there was another one that had bid him eat from the tree of knowledge.

Far from the overwhelming repression of von Neumann's masculinist objectivity, Turing's visions of digital intelligence included minds which were fluid, social, and reflected an enormous range of human emotional experience.

Both Turing and Lovelace contradict the organicist notion that digital systems are somehow inherently opposed to life and human community. In the hands of either one, von Neumann's self-reproducing automata might have been a way to increase ties to nature and culture. But for von Neumann this was a way to escape the chaos of life, a way into pure, abstracted order. And as an escape from life, it could only lead to death.

One of my students, a computer science major whose experience as a youth in Korea reminded me of von Neumann's Hungarian experience, told me about his own desire to see self-reproducing automata created. He said that such artificial intelligence was crucial "because after we destroy ourselves with nuclear weapons, they would be a pure race of beings, driven solely by logic, and therefore mankind will have ultimately succeeded." There may have been some similar thoughts in von Neumann's mind. During the Hixon Symposium (von Neumann 1951) he was asked if computing machines could be built such that they could repair themselves if "damaged in air raids," and replied that "there is no doubt that one can design machines which, under suitable circumstances, will repair themselves." It is likely that his work in 1954 on nuclear radiation tolerance included machine operation as well as biological effects. Heims writes that he appeared to view "nuclear weapons as a means to salvation" and that they pro-

vided him with "a feeling of immortality as well."

If von Neumann did have fantasies about his mechanical progeny surviving the nuclear purging of organic life, it would seem that he went to some lengths to ensure that the automatons carried no taint of our chaotic impurity into their new world order.

> He was worried; he wanted no mention of the "reproductive potentialities of the machines of the future" to the mass media. It may be that he regarded his own fantasies, if any, about self-reproducing machines... as a very private matter. To Wiener he wrote admonishingly, "I have been quite virtuous and had no journalistic contacts whatever" (Heims pp 212-213).

Wiener's response did not help his worries concerning the future purity of his progeny:

> He wrote lightheartedly to von Neumann, "I am very much interested in what you have to say about the reproductive potentialities of the machines of the future. As Grey Walter in England has just made a machine with ethics of its own, it may be an opportunity for a new Kinsey report." Von Neumann, so famous for his jokes and funny stories, did not think this was amusing (pg 212).

Wiener did not stop here; in *God and Golem inc*. there are several comments which play on von Neumann's work. Part of the book is devoted to demonstrating how machines might reproduce through chaos: here he suggests that the world is non-linear and stochastic, and that real living systems must use chaos and indeterminancy as a part of their survival. He pointed to the absurdity of von Neumann's game theory as too rigid even for computers to use, and took note of the ultimate end such rigid fear of chaos would lead to.

> Indeed, I have no reason to suppose that such formalized versions of [game theory] are not already being established as models to determine the policies for pressing the Great Push Button and burning the earth clean for a new and less humanly undependable order of things.

In August of 1955, at the height of von Neumann's attempts to quell public fears of radiation danger, his tightly ordered micro-worlds of the sub-atomic and the genetic collided: the fallout from the numerous nuclear weapons tests he attended had produced a metastasized bone cancer, and chaos finally won out.

1.9 Conclusion

In *The Rise of Systems Theory,* Lilienfeld (1979) critiques the information sciences as both fraudulent and inhumane. His critique focuses on two elements: the guiding of society by a small intellectual elite, rather than self-guidance, and the increased rigidity of society through formal systems. While the example of von Neumann may well support such critique, this essay should contradict Lilienfeld in two important ways. One is simply in the counter-example of Wiener: his cybernetics was centered around increasing self-guidance, and making use of information that is not in the formal symbolic system. The second might be viewed as a deconstructive critique: "self-guidance" is not necessarily liberating, and formal systems are not necessarily oppressive.

As the examples of Lovelace and Turing demonstrate, a formal digital system can provide unexpected openings into the hegemonic forces around us and inside us. Contrarily, Wiener's colleague Bush used his background in analog computation to launch himself into a military career (Bush 1949).* And self-reference has played a wide variety of roles: the dominating negative feedback of social norms in the *tzadeket;* the threatening chaos of positive feedback in the golem; the recursive computation of a math-fairy; the abstracted hiding place for a threatened gay; and the ever-changing dialogue of people and machines. Analog and digital, positive feedback and negative feedback, chaos and order: none of these are inherently good or bad. Information systems of sufficient complexity always become expressive media; but the meanings they express arise from their human context.

For Wiener and von Neumann, this mapping between various cultural dimensions and their scientific work was driven by the historical period of modernism, a period

*Even after analog computation was given up for digital, the need for special-purpose analog devices continued, and Bush was involved in the precision-manufacture problem which was closely related to analog technology.

which generated the material conditions needed for the birth of cybernetics. Thus their cybernetics was a modern one. Von Neumann's formal microworlds -- the subatomic system, the game theory world, the bacteriophage, the automaton -- were more than obsessions, they were meant to represent how the world really is, in a fundamental sense: a world which is determinant and rule-governed despite any appearances of chaos. Wiener's notion of the world was that despite our ability to find rules and laws, it is essentially indeterminate, driven by chance and riddled with complex non-linearities that defy understanding by formal symbolic logic. Neither of them considered the possibility of something both deterministic and chaotic.

I have qualified the Wiener -- von Neumann duality as *modern* cybernetics because it both created and reflected social modernity. In the following chapter we will begin with an explication of the ways in which Wiener's feedback and analog systems wove themselves into the counter-culture of the 1960s, and the integration of von Neumann's digital systems into what was then called the military-industrial establishment. But just as the modernism of the 1940s allowed for the creation of cybernetics, by the late 1970s this technologized culture, a post-modernism, reflected new technological discoveries: a *post-modern** cybernetics. And as a mirror reflects its image in reverse, this post-modern cybernetics shows some surprising reversals. Chaos is seen as deterministic, and advances in formal logic theory are produced by stochastics. Decentralized feedback systems become a new military strategy, and the youth counter-culture gives up its organic farming communes for the digital communion of urban machines. My analysis will mark out three different moments in this transition. They are culturally signified by hippies (cult of the organic), punks (cult of the artificial), and new agers (cult of the organic-artificial synthesis); in science we find reversed movements in chaos-order

*See Jameson 1984 for a brief summary of some possible characterizations in this historical period of simulations, surface, genuine artifice and fake humanism.

dualisms which parallel these same historical moments.

Historical context is not the sole determinant, and this chapter has concentrated on how personal identities are also deeply intertwined with even the most "objective" of sciences. The play of sex and imagination, ethnicity and experience, emotion and social standing produce the equations and machines we sometimes see as innocent and inevitable. But even these personal forces resonate with our grand historical moments: the rituals of genderized Judaism that I have written into Wiener and von Neumann have found a post-modern chaos of their own.

> Ritual is unique, however, in having disorder as its essential quality. Deliberate destruction of the social order as presently constituted and reconstruction, transformation culminating in reordering -- this is the significance of ritual. Within a traditional Jewish context, ritual must disorder and reconstruct both the social and spiritual divisions of the universe, realigning the realms of sacred and profane, gashmiut and ruhniut, male and female, fiction and myth (Satlof 1983).

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Chapter 2: Popular Culture and the Rise of Postmodern Cybernetics

2.1 Overview

The last chapter portrayed the origins of cybernetics in terms of the split between Norbert Wiener and John von Neumann. There were two dimensions to their cybernetics which focused their personal differences: recursion and the analog-digital dichotomy. For Wiener the recursive self-control of feedback came to signify humanist self-governing of individuals and societies. For von Neumann self-reference was a site of trouble, of Gödelian undecidability and chaos. In analog representation Wiener saw a path toward organic unity; analog systems signified flexible, informal social dynamics and an ethical holism embodied by Nature. In digital representation von Neumann saw predictability, the imposition of control over unruly or slippery systems through artificial formalization. I have taken pains, however, to show that these associations between the two cybernetic dimensions and their corresponding social/ethical dimensions are not inherent. By examining personal histories of these two scientists, as well as those of their predecessors, we can find many contradictions -- examples of liberation in digital order, and oppression in analog chaos -- and we can see some of the ways in which the cultural backgrounds of individuals have *created* these ethical attachments.

In this chapter we will examine this same interaction between the two cybernetic dimensions and their cultural significations on a much wider scale. Rather than detailed examinations of individual lives and meanings, we will look at the ways in which entire scientific communities of a particular era converged in this technical-cultural interaction. Throughout the many disciplines and applications connected to cybernetics in its youth (1950s to 1960s), there was a persistent and often dramatic polarization between organic humanists, promoting nonlinear analog feedback systems, and rationalist authoritarians,

who favored linear digital hierarchies. The association was not absolute; there were some digital humanists and some analog authoritarians. Nor was the division completely discrete - it is best to think of this not in Kuhn's terms of separate, encapsulated paradigms, but rather as a gradient with attracting pulls at either end. But by 1967 it was clear that one was expected to go with the flow, on one side or the other. Conferences, instrumentation, industrial practices, academic institutions, citation clusters, and other aspects of intellectual and material support in the scientific community -- resources which are always hotly contested by the cultural forces embodied in science -- were split by the extreme social tensions of the era.

Thus the bifurcation was not simply an independent development within cybernetics; it was deeply influenced by the events of "the turbulent decade," by a counter-culture which posed itself as organic chaos pitted against artificial order. But the counter-culture of the sixties was itself influenced by cybernetics; there was a circular causality between the two.

The following text will refer to this historical period as *modern,* defining the social condition of modernity in terms of the ethical constructions around humanism and organicism. The oppositional practices which emerge from these ethical constructions will allow us to examine their material expression, and we will use this as a basis for exploring the polarization of modern cybernetics. But a drastic shift in these oppositional critiques occurred during the seventies; a shift in which both humanism and organicism lost much of their status as the ground of ethical meaning. This new era will be referred to as *post-modern;* and the new developments in the information sciences of the time as post-modern cybernetics. The notion that massive intellectual eras suddenly come and go is, admittedly, a bit absurd, and to keep its caricatured nature in mind I've made the following designations. Since the "summer of love" is often seen as the height of the sixties counter-culture, July 7, 1967 will marked as the high point of modernity, and July 7 1977

-- the starting point for punk rock and hip-hop -- will be the opening date of the postmodern era. Reversing the Natural analog orientation of the sixties, Post-modern counter-culture promoted digital artifice, and it was at this moment that the "military-industrial establishment" decided to welcome chaos.

2.2 Pacé Lilienfeld

As mentioned in the previous chapter, Lilienfeld (1974) writes in direct contradiction to my assertions: he sees all of the information sciences (which he groups together under the title "systems theory") as authoritarian conspiracies, a plan for technocratic control and promotion of a self-interested scientific elite. I have argued against his view both because it erases the humanist efforts of many scientists, and because it fails to critique humanism itself. Lilienfeld's analysis is valuable, however, in that it highlights the von Neumann side of cybernetics, and thus serves as a guide to those seeking the other end.

Lilienfeld's characterization of all information sciences as politically oppressive depends on two moves: The erasure of the analog/digital distinction, and an insistence that all recursive networks are centralized hierarchies.* These are by no means devious illusions on the part of Lilienfeld - they stem from not only long standing epistemological traditions, but are also promoted by many information scientists themselves.

This erasure of the analog/digital distinction is crucial to Lilienfelds's critique of Wiener. In response to Wiener's suggestion that human languages are more digital and other animals more analog, Lilienfeld ridicules the notion of analog representation and implies that Wiener invented it as a way to denigrate certain human languages as more

*The question of when recursion results in chaos and when it does not is complex, and for the most part I will simply contrast imposed control from outside with recursive control from within. This runs the risk of reversing Lilienfeld's bias, and giving the false impression that all recursive networks are decentralized. The question will be taken up in detail in chapter 4.

primitive (pg 78). It is certainly true that analog communication opens up the possibility of primitivism, but this is a complex issue which (as we will see in chapter 4) must be fully engaged.

Analog computation is also dismissed by Lilienfeld, particularly in the field of machine intelligence. For von Neumann's digital hierarchies (essentially the standard digital computer, also known as "von Neumann architecture"), machine intelligence meant AI -- software in which long lists of attributes and "if-then" rules were exhaustively searched. Lilienfeld correctly points out that such attempts have been miserable failures, not only in terms of performance but also failing in similarity to the way biological brains work. Since his evidence for the inadequacy of AI methods includes EEG brain studies, which show "complex wave patterns [which] cannot be resolved to any unique set of components," and the work of Karl Lashley, demonstrating decentralization in the cerebral cortex, one might expect that Lilienfeld would appreciate the possibilities of Wiener's "neuromimetic" alternative, decentralized analog feedback networks. But these are disregarded at the end of his AI discussion as simply "further refinements along these lines." Similarly, Wiener's thoughts about political decentralization are dismissed as "stability to be introduced by scientific management of society."

While Lilienfeld makes a poor, if not self-contradictory case for political oppression lurking beneath Wiener's cybernetics, he is a bit more on target when it comes to the general systems theory of Ludwig von Bertalanffy. Von Bertalanffy (Davidson 1983) was an Austrian biologist whose theories ran counter to both mechanistic behaviorism and genetic determinism. His opposition to racist theories of biology were a source of hardship during the Nazi occupation; his works were included in some of their bookburnings. During the post-war Soviet occupation he was blacklisted because of his opposition to Lysenkoism. He left for the US, and immediately ran into trouble with McCarthyist bureaucrats, who demanded to know why his bylines had appeared in Soviet

publications.

Von Bertalanffy's attempt to create a holistic theory of general systems, based on his experiences in the self-organizing attributes of biological systems, was specifically intended to oppose the politically oppressive theories of genetic determinism and Skinnerian behaviorism (Grey 1972). In a way this was revenge: politics had tried to take over his biology, and now his biology would overtake politics. But in attempting to generate an abstract theory that could transcend ideology, he simply tended towards the apolitical. While occasionally expressing his personal support for liberal causes, such as opposition to the war in Vietnam, his systems theory was publically converted into a methodology for technocratic control. His reaction to such oppressive use was quite cool: they simply didn't get it right, and proper understanding of general systems theory would lead to only humanistic use.

Lilienfeld does not see any ambiguity (or tragedy) in von Bertalanffy's work; to him it is just another program for mechanistic hierarchy. It is odd that in critiquing the theory for its lack of human dimensions, he fails to examine the human being who created it. Lilienfeld is quite correct when he points to the constant use of the term "hierarchy" for descriptions of all systems. But the problem is not that the system theorists saw everything as centralized -- on the contrary, they were quite interested in the explication of self-organized, decentralized processes. The problem was a lack of commitment, an unwillingness to take a stand on exactly what it meant to have a non-centralized structure -- thus the application of "hierarchy" to every system description. Unlike Wiener, von Bertalanffy tried to refuse responsibility for outcome of his theories, and maintained a middle-of-the-road approach which was reflected in his technical work.

In the case of Wiener, Lilienfeld is far off the mark; for von Bertalanffy he gets much closer. At the von Neumann end, he is in his element. The techniques of linear programming, game theory, operations research, decision theory, and other reductionist

systems are indeed "the 'natural' ideology of bureaucratic planners and centralizers and both expresses and fosters developments along these lines" (pg 266). Here his analysis is well documented and demonstrates a close parallel between technical and political process.

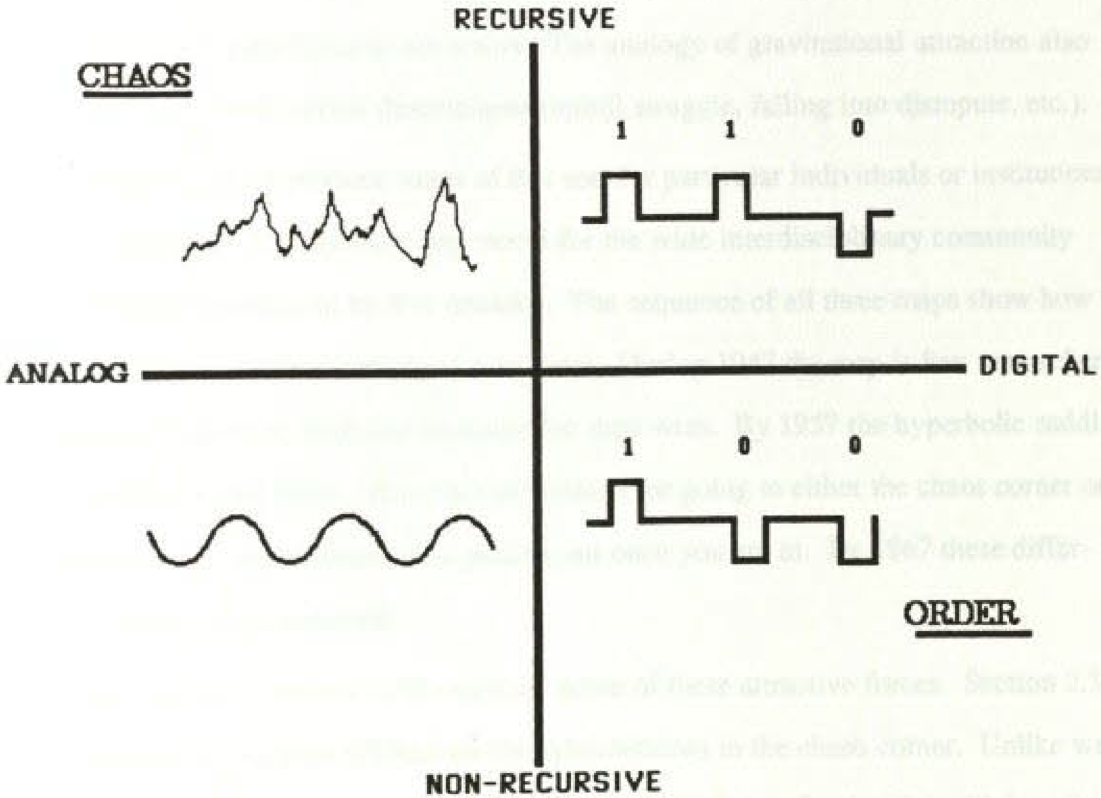
The paradigm-gradient I have discussed, from Wiener's chaos to von Neumann's order, is illuminated by the contradictions in Lilienfeld's work. In his effort to demonstrate the oppressive social praxis of the information sciences, he needs to misrepresent -- or simply leave out -- those scientists and technical constructs which were allied with anti-authoritarian politics: the degree of this elision decreases as we move along the gradient from chaos to order. There are two moves to this misrepresentation - erasure of the analog/digital distinction, and an assumption that all recursive networks are centralized hierarchies - and similarly two dimensions to the chaos-order gradient. This two-dimensional portrait is illustrated in figure 2.1a.

In this mapping we can place (with lots of guesswork) technologies, processes or theories at their appropriate point on a two-dimensional surface. Not only does this permit different combinations between dimensions, it also allows fine distinctions of degree. For example, a highly distributed network of feedback elements would be at the top of the graph, since it is the most recursive configuration. A network in which local processors are allowed to make local decisions, but one central processor gathers the information and has the final say would be in the middle. Finally, a purely von Neumann architecture, in which one processor does all the decision-making, would be at the bottom. Similarly, we can describe systems which vary from pure analog, on the extreme left of the graph, to analog-digital hybrids in the middle, to pure digital on the right.

One advantage to this kind of mapping is that changes through time can be traced as trajectories along its surface.* For example, von Neumann's biocybernetic modelling

*A similar mapping, the 'semiotic square' (Greimas and Rastier 1968) has been used in literary

Figure 2.1a: Two dimensions of chaos



began with Weiner's analog feedback model of neuromuscular systems, but moved to a model of digital recursion (genetic reproduction) -- a path from left to right in the top half of the graph.

Another advantage of this map is that it can be modified by a third dimension indicating forces of attraction at specific locations of the map (fig 2.1b). This is best conceived in terms of gravity -- individuals on this bumpy surface would be like water drops, flowing downhill. We are not simply free to move about this space as we please, but are pulled into these paradigmatic attractors. The analogy of gravitational attraction also coincides nicely with verbal descriptions (uphill struggle, falling into disrepute, etc.).

While we could produce maps of this sort for particular individuals or institutions, the maps in figure 2.1b indicate my model for the wide interdisciplinary community affected by cybernetics in its first decades. The sequence of all three maps show how this shared paradigmatic space changed over time. During 1947 the map is flat; researchers are free to experiment with any combination they wish. By 1957 the hyperbolic saddle-shape begins to take form. There are attractions for going to either the chaos corner or to the order corner, and difficulties in getting out once you are in. By 1967 these differences are sharply accentuated.

The next two sections will examine some of these attractive forces. Section 2.3 will describe the political affiliations for cyberneticists in the chaos corner. Unlike water drops, these include both willing and unwilling participants. Section 2.4 will describe the cybernetic affiliations of political activists. Here too individuals are not simply passive objects, driven by unseen forces, and the resistance to cybernetics -- or even science itself -- plays an important role. But in both cases it is the shared meanings which are most

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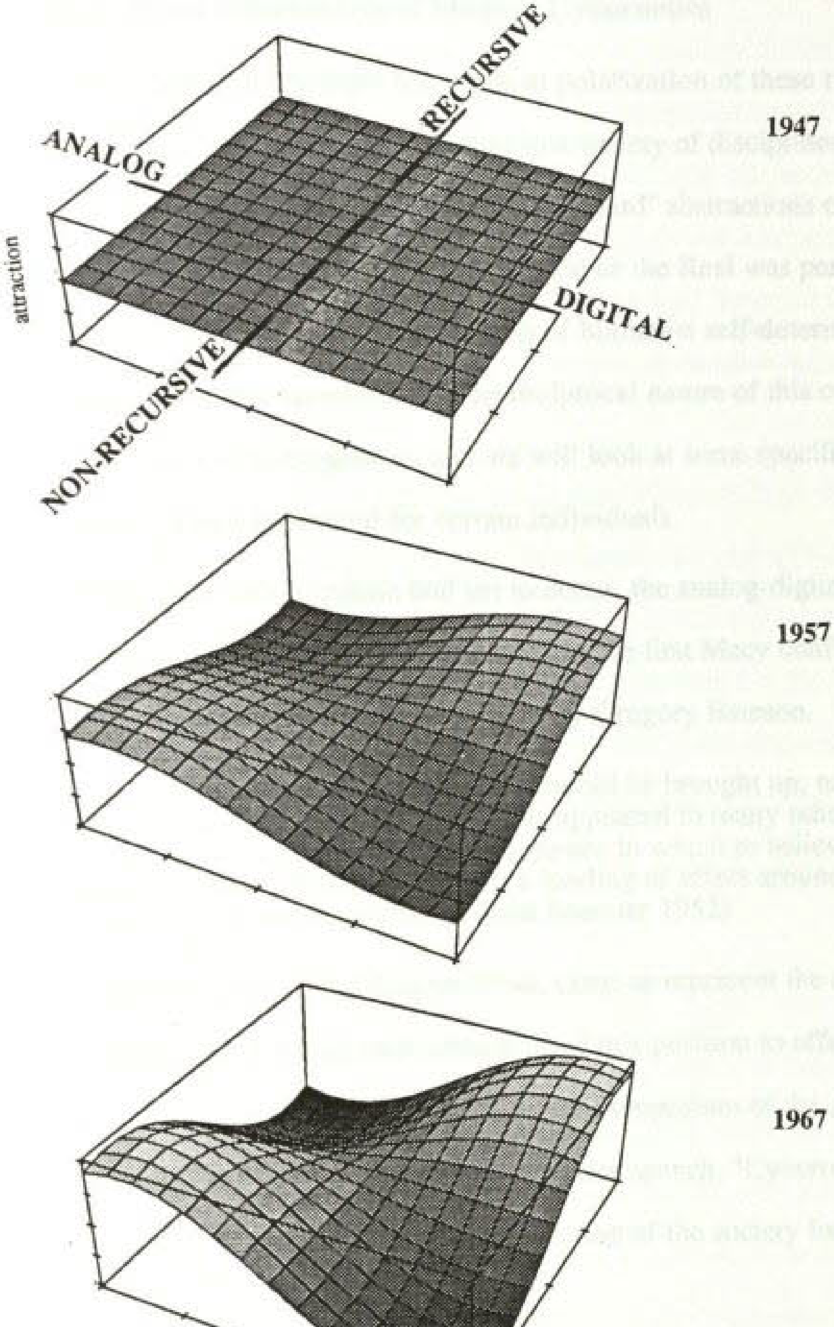
theory, but here the tendency is to map oppositions of static signs. Even where such maps are allowed to show traces of meaning dynamics (eg Clifford 1988 pg 223), their allegiance to the 'arbitrariness of the Sassurian signifier' precludes the graphing of physical changes as a function of the changes in meaning.

Figure 2.1b: Paradigmatic bifurcation in cybernetics



important, and the ways in which cybernetics and the cultures of oppositional politics have been mutually constructed constitute a surprising historical portrait.

2.3 The Political Polarization of Modern Cybernetics

This section will highlight the political polarization of these two cybernetic dimensions by examining the work of scientists in a variety of disciplines during the 1960s. Moving from the 'soft' human sciences to the 'hard' abstractions of mathematics, we will see that the romantic organicism of the Natural or the Real was persistently attached to analog systems, and that the recursive loop of humanist self-determination was implicated by its cybernetic equivalents. The reciprocal nature of this coupling does not mean that the linkage was homogenous, and we will look at some specific differences in the way these two maps interacted for certain individuals.

Although the politicization had yet to occur, the analog-digital dichotomy was quickly established as field for contestations in the first Macy conferences of the late 1940s. This was commented on at the time by Gregory Bateson.

> There is a historic point that perhaps should be brought up; namely, that the continuous-discontinuous variable has appeared in many other places. I spent my childhood in an atmosphere of genetics in which to believe in 'continuous' variations was immoral. ...There is a loading of affect around this dichotomy which is worth our considering. (von Foerster 1952)

Bateson, together with Margret Mead, came to represent the anthropological sciences for cybernetics. Mead took advantage of this position to offer some self-referential perspectives on cybernetics at the first Annual Symposium of the American Society for Cybernetics in 1962. She began her introductory speech, "Cybernetics of Cybernetics," with some memories of the foundational meeting of the society for General Systems Theory.

> I suggested that, instead of founding just another society, they give a little thought to how they could use their theory to predict the kind and size of society they wanted, what its laws of growth and articulation with other parts

> of the scientific community should be. I was slapped down without mercy. Of all the silly ideas, to apply the ideas on the basis of which the society was being formed to *Itself!* (von Foerster et al 1968 pg 10)

Mead was already famous for her blending of scientific analysis with cultural critique, dating from her refutations of theories on the biological determination of gender characteristics in the 1920s. In this talk she warned against the unreflective or irresponsible use of cybernetics, pointing to L.F. Richardson's pacifist approach to mathematical models of warfare, and Edmund Bacon's use of cybernetics in participatory city planning as alternatives. Mead's articulation of the ironic lack of "circular self-corrective systems" in the science of circular self-corrective systems underscored the impending politicization of recursion in cybernetics.

In addition to Bateson's background in psychological field studies, there were several academic psychologists involved throughout the rise of cybernetics and its related disciplines. Kurt Lewin held a prominent position in the early meetings, primarily due to the similarity between his gestalt psychology perspective and the holistic orientation of many of the cyberneticists. Although Lewin's early work ostensibly separated a pure science from practical applications, his studies of prejudice against minorities and advocacy of grass-roots activism coincided with his abstract conceptualizations of a "topological psychology" (Heims 1978).

The bridge between cognition and material physiology was more in the province of cybernetics proper, and was launched by the classic paper "What the Frog's Eye Tells the Frogs Brain," written by Lettvin, Maturana, McCulloch and Pitts in 1959. This paper radically decentralized notions of biological information processing, since it showed that the frog's eye selected the visual patterns which were sent on to the brain (in particular those indicating a moving object). McCulloch (1945) had previously introduced the term "heterarchy" to describe this decentralization, noting the etymology of "hierarchy" in religious rule. He extended this connection in his essay "The Past of a Delusion," in

which he critiqued both capitalism and communism for their authoritarian epistemologies (in Freud and Marx respectively, with additional disparagement of Freud's sexism). Maturana was politicized from the start, due to his Chilean origins and opposition to the right wing; together with fellow Chilean Francisco Varela they have continually emphasized the convergence of cybernetic perspective with a holistic cultural critique.* Like McCulloch, they proposed an isomorphism between the humanist goal of self-governing people and the cybernetic analysis of recursive decentralized networks, which they termed "autopoiesis."

Although Varela did not meet Maturana until 1965, he had already come to a similar outlook (Thompson 1988 pg 106). In addition to decentralization, Maturana and Varela have proposed that analog systems hold a special ability for "natural" information processing. This is connected to a romanticist or organicist view of human ills as generated by the artificiality of our digital systems, with Nature holding the solution. The connection to romanticism hinges on their modernist perspective of analog systems. They are often not viewed as representation at all, but as the Real. This is most strongly stated by Varela, in what he terms the "nonrepresentationist point of view."

> There is no distance, not even the distance between an it and its picture, which makes it possible to ask how accurate a representation the picture is.... To me, the chance of surviving with dignity on this planet hinges on the acquisition of... a radically different epistemology. (Varela 1987 pp 48-49)

Although this quote is from a 1987 publication, it is based on Varela's thinking in the 1960s, and he goes on to point out that the bias toward digital representation (in his terms "representationism") was new at the time.

*Their view on Chilean politics can be found in Varela 1979; here Varela contrasts the analog/decentralized social cybernetics of their radical view with the analog/authoritarian social cybernetics of Howard Odum (see Taylor 1988 on Odum). On the actual use of cybernetics in Salvador Allende's government, see Beer 1975 pg 3.

> There was nothing in the early days of modern neuroscience to indicate that it would become fascinated with representationism. As a very clear example, consider the following quotation from an important journal, as late as 1957: ..."In the investigation of nervous activity the physiologist makes marks on the rims of the rims of the wheels of their activity. So fascinating is the process of marking... that the circle itself is forgotten.... Because of this unperceived tendency we have the scientific structure of "localization" and "representation" of functions in the nervous system. (Varela 1987 pg 60).

Even in mathematics, the most abstract field connected to cybernetics, there were researchers who made a connection between cultural critique and holistic technical concepts. Ralph Abraham (personal communication) noted that at UCB the entire math department seemed divided between those concerned with models for analog systems (eg topology), siding with the student activists, and a more conservative or "apolitical" group (eg Everett Bishop in constructive analysis) whose studies tended toward more linear, reductive systems. Abraham's own experiences bridging hippie culture of the 1960s with his dynamical systems theory are well known (Abraham 1987). Gleick (1987) describes the efforts of Berkeley mathematician Steve Smale in creating the first recursive maps of dynamical systems ("horseshoe maps") at the same time he helped Jerry Rubin to organize the anti-war train blockades (as well as attempting to protest against the Soviet invasion of Hungary during his visit to the USSR).

In addition to those already mentioned, there were many others - Kenneth Boulding in econometrics, Tolly Holt (director of Advance Systems in Princeton), C. H. Waddington in biology, Karl Pribram in neuropsychology, and Magoroh Maruyama and Heinz von Foerster in cybernetics proper (to name a few) - who fell into this connection between the holistic perspective in cybernetics and the holistic critique of modern society. There was a common linkage between romanticism and analog systems, and humanism and recursive systems, throughout this side of the cybernetic community.

The conservative counter-part to this Wieneresque holism would be the advocates of digital hierarchy. Here we see an association with a rationalist or progressivist

affirmation of the artificial, and an authoritarian love for imposed control. I will not repeat this history, since it is already well-developed in Lilienfeld and Edwards. Indeed, to my mind their story is too well developed: the digital hierarchists managed to take control of much of the funding and institutions for cybernetic research during the 1960s, and made an effort to suppress the legitimacy, if not the existence, of the analog decentralists. It is ironic that Lilienfeld and Edwards both support this erasure in their historical accounts.

In accusing others of erasing the presense of holistic humanists within cybernetics, I run the risk of repeating this error, and avoiding mention of those few who adopted analog decentralism in their technical studies, but advocated a rigid authoritarianism in their politics. In addition, I should also mention the few technical digital hierarchists who supported holistic cultural critique. Among the latter, the best instance is probably Anatol Rapoport, who was a founding member of the game theory school but supported peace efforts and anti-authoritarian politics. Rapoport would eventually create a game theory model demonstrating that cooperation and trust were superior strategies (Axelrod 1984).

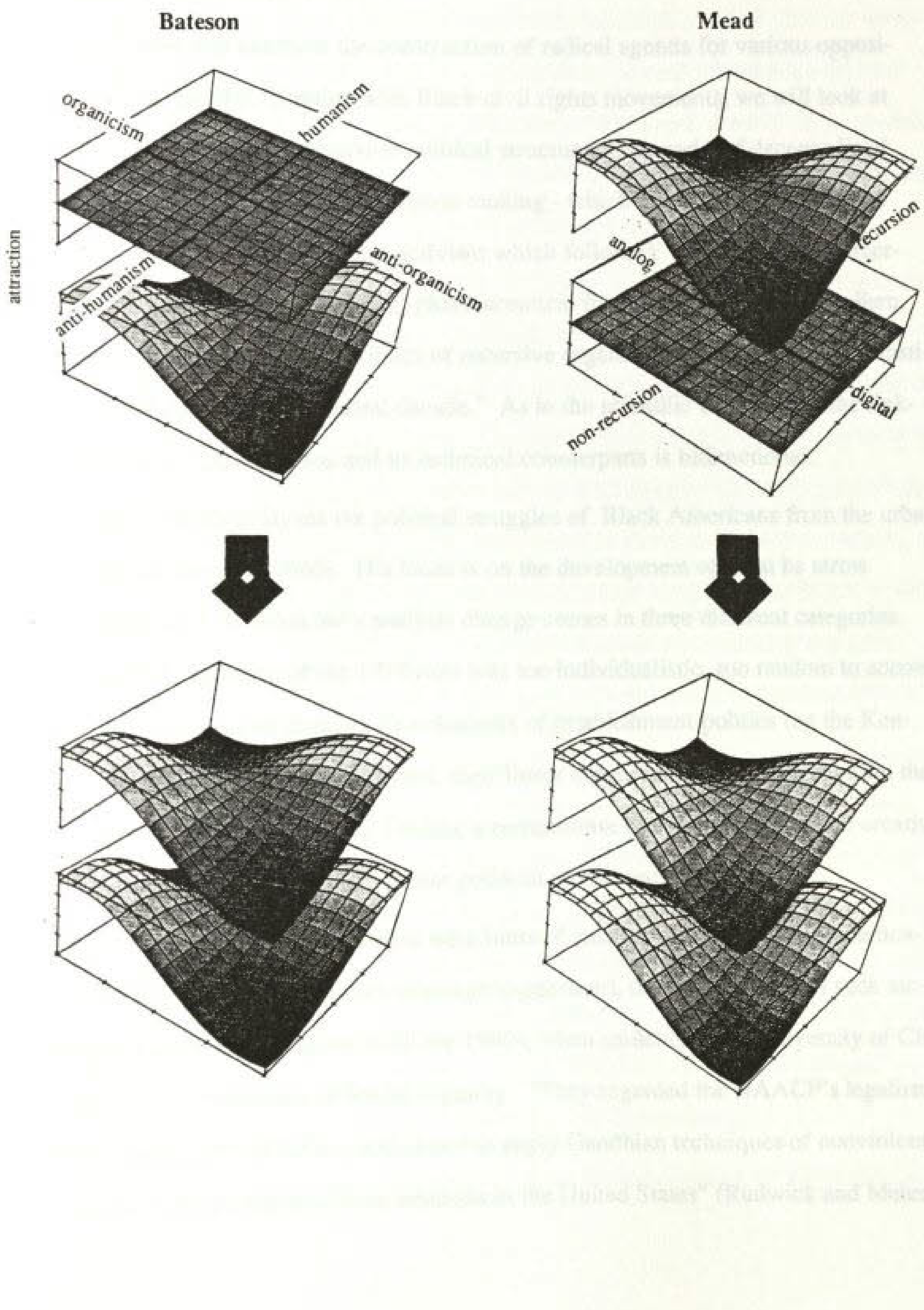
An interesting example of political conservatism among analog decentralists is documented in the transcripts of a cybernetics conference organized by Bateson in 1968 (published in a detailed, personal account by his daughter; M.C. Bateson 1972). Here, at the height of modernity, Bateson, McColluch, Holt, and others less centered in cybernetics (such as ecologist Barry Commoner) were surprised to find that their colleague, industrial cyberneticist Gordon Pask, was not ready to slide into their political holism; in fact he was kicking and screaming all the way down. While Commoner and Bateson made the usual connections between the goals of humanist ethics and natural analog feedback (now expanded to include Black history, urban recycling and the !Kung), and Holt read from Zen philosopher Alan Watts, Pask constantly re-asserted his need for professional authority and managerial practice (see ch. 11).

The presense of these exceptions, Rapport and Pask, serve two purposes here. One is that they help to remind us that there is not an *inherent* connection between the cybernetic dichotomy of chaos/order and the associated political oppositions; rather the connection is a result of historical and cultural forces. The second is that they serve as markers for the flow of social forces these individuals are resisting. Just as packets of dye are used to make visible the currents in a body of water, the struggles of Rapoport and Pask illuminate (both ideologically and technically) the polarizing tug of chaos/order within the scientific community.

We can imagine a second map of political holism/reductionism oppositions coupled to the technical map of chaos/order oppositions. Figure 2.1c illustrates this coupling for Gregory Bateson and Margaret Mead. Mead's political involvement was a long-term commitment for her; the technical dimensions were not polarized for Mead until after she understood how the politics was going to couple with this cybernetic map. For Bateson the temporal causality was the reverse. Ken Norris (personal communication) notes that from his own experience with Bateson, cybernetics seems to have been an opening into the political arenas he had previously avoided; his daughter has made similar implications (M.C. Bateson 1984 pp 217-220). Yet Bateson was quite fixed on the significance of both analog representation -- rebelling against his father's waring that "to believe in 'continuous' variables was immoral" -- as well as recursion (as exemplified in his pre-cybernetic work on "schismogenesis"). His own political map was flat until he saw how it's hyperbolic humanism could match his own cybernetic topology.

In the case of the scientists, coupling between the political map and the cybernetic map was often quite different for each individual. Collectively, the outcome was the same: chaos on the side of the radicals, order on the side of conservatives. But this coherence cannot be explained by looking solely within the scientific community. In the next section we will examine the same coupling of maps as it was expressed in the

Figure 2.1c: Cybernetic politics in Bateson and Mead



political subcultures.

2.4 Cultural Chaos in the 1960s

This section will examine the construction of radical agenda for various oppositional groups of the 60s. Starting with Black civil rights movements, we will look at some of the motivations for recursive political structures - networks of decentralized community groups and interactive decision making - which came to characterize the majority of the wide-spread political activism which followed. The subsequent emergence of a "counter-culture," blending pharmaceutical freedom with artistic populism, added an analog romance to the politics of recursive organization. Together they constituted the ingredients for a "turbulent decade." As in the scientific community, the linkage between this cultural chaos and its technical counterparts is bidirectional.

Waskow (1967) analyzes the political struggles of Black Americans from the urban riots of 1919 to the early 1960s. His focus is on the development of what he terms "creative disorder." In Waskow's analysis change comes in three different categories. The unstructured violence of the 1919 riots was too individualistic, too random to accomplish any definitive social change. The channels of establishment politics (eg the Kennedy administration) were too structured, their linear order restricting change within the limits of White liberal acceptance. Finding a compromise of structured chaos, of creative disorder, was the key to releasing a potent political movement.

Waskow notes that although there were hints of creative disorder in 1919 (particularly James Weldon Johnson's work stoppage suggestion), the development of such tactics did not find sufficient support until the 1940s, when students at the University of Chicago formed the Committee of Racial Equality. "They regarded the NAACP's legalism as too gradualist and ineffective, and aimed to apply Gandhian techniques of nonviolent direct action to the problems of race relations in the United States" (Rudwick and Meier

1970, pg 10). Eventually this became a national federation of groups, the Congress of Racial Equality (CORE).

By 1955 CORE membership had declined, but in the south creative disorder resurfaced following Rosa Park's defiance of bus segregation. In response to her arrest the Montgomery Women's Political Council recommended a boycott; the role of the church as an organizational framework and the spread of antisegregation protests eventually led to a new organization, the Southern Christian Leadership Conference (SCLC).

In 1960 four first year students from A & T College in Greensboro, North Carolina took seats at a segregated lunch counter. They had not heard of previous sit-ins by CORE and NAACP youth groups, but were inspired by the successful use of nonviolence in the SCLC (Solomon and Fishman 1964). Through mass media the idea of the sit-in quickly spread throughout towns where there were Black colleges. CORE began to hold training sessions in nonviolence, and SCLC secretary Ella Baker organized a conference for college groups involved in the sit-ins with the thought of developing an SCLC youth group. But students were not interested in an official connection to either group (Zinn 1964), and formed an independent Student Nonviolent Coordinating Committee (SNCC).

Stroper (1977) describes SNCC as lacking a formal ideology. "Its members plucked ideas from the works of Albert Camus, Karl Marx, Mao Tse-Tung, Malcolm X, Frantz Fanon and others." Their focus was on "possibilities for the self-organization of Black people in the South .... a politics that was more decentralized, idealistic, intimate, non-coercive...;" and a result of this focus was "the rejection of all forms of bureaucracy and formal leadership structures." Waskow points out, however, that this was not done under moral commitment to Gandhian nonviolence; rather "the choice not to use violence was based on tactical political decisions" for most of the SNCC members.

It was in this atmosphere of creative disorder, of decentralization over hierarchy and

intimate informality over formal representation, that many White college students began their careers as radicals (Miller 1987). In 1960 the Students for a Democratic Society (SDS) was just one of many university organizations, but their plan for a conference on human rights coincided with the sudden birth of the SNCC. Energized by those events, the organization attracted several talented individuals: Sharon Jeffrey, Alan Haber Bob Ross, and aspiring journalist Tom Hayden. As SDS field secretary, Hayden worked with SNCC, gaining credibility as an activist as well as an understanding of the SNCC political philosophy.

As Fraser (1988) notes, "the student organization's close links with SNCC were the first steps to prominence.... The qualitative leap came, however, when SDS translated SNCC's ideology into one capable of mobilizing White students...." This translation was deeply influenced by the work of C. Wright Mills and Arnold Kaufman. In Mills they found an academic voice for a radical critique of centralization and bureaucracy. In Kaufman there was a critique of the representative system of government, and a proposal for "participatory democracy." This term varied widely in interpretation, but the meanings generally revolved around the notion that formal systems of representation were too artificial, distancing people from more natural interactions and inviting technocratic rationalism.

These two holistic foundations, humanist anti-centralization and organicist anti-representation, were given official status through their use in the SDS manifesto, the *Port Huron Statement* (June 1962):

> How shall the "public sector" be made public, and not the arena of a ruling bureaucracy of "public servants"? By steadfast opposition to bureaucratic coagulation, and to definitions of human needs according to problems easiest for computers to solve... and, most important, by experiments in *decentralization*, based on the vision of man as master of his machines and his society (Miller pg 364; italics in the original).

The image of the digital computer invoked both hegemonic, hierarchical centralization and alienating, artificial representation. It also made an easy target. Even the mainstream press ridiculed the emergence of a "do not fold spindle or mutilate" society, and fears of the machine as master were often voiced in popular media (eg science fiction). The solutions to these problems were not as easy however. What, exactly, did "decentralization" mean - did it call for the *absence* of structure? Similarly, what forms of communication were not formal - did this call for an absence of representation? The ambiguities were at the center of the difficulties for activists attempting to put these two principles into practice. Decentralization often seemed to dissolve into unstructured randomness.

> This crazy-quilt pattern of activity - leafleting, tutorials, reading groups - was, in part, the result of a decision made a few months before. At a meeting in Columbus, Ohio... the SDS... had agreed to launch a number of different experimental projects on a decentralized, campus-by-campus basis. Some of these projects had come to fruition; many more had not. ...But the chaotic pattern of activity also reflected the strategic ambiguities left unresolved by the *Port Huron Statement* itself (Miller pp 166-167).

The question of representation was more complex. When asked for his definition of "participatory democracy," Hayden said that to him it meant "number one *action;* we believed in action. ...Having a democracy in which you have an apathetic citizenship, spoon-fed information by a monolithic media... was a declining form of democracy" (Miller pg 144). This contrast between artificial media and authentic physicality is often suggested by descriptions of the need for consensus meetings. The "face to face" experience of speech intonation, gesture, and facial expression -- indeed the entire physical presence -- "would allow individuals to show themselves to others as they really were" (pg 208). Once again, we see a romanticist effort to bypass representation by avoiding symbolic encodings (ie texts), accompanied by the illusion that analog representation is somehow closer to the Real.

Miller notes that both ambiguities of SDS policy were problematic to Hayden at the time:

> The tension in Hayden's thinking suggests... not one, but two distinct political visions: the first is of a face-to-face community of friends sharing interests in common; the second is of an experimental collective, embarked on a high-risk effort to test the limits of democracy in modern life (pg 146).

The sources for these ideas were partly from traditional political philosophy (Mills, Kaufman) and partly from political activists (CORE, SNCC). But in addition to these there was a third source: applied science.

SDS had started as the student chapter of the League for Industrial Democracy (but changed its name since "SLID" was deemed undignified). Althought the LID already had some technological affiliations, there does not seem to be any evidence that this was a conceptual resource for SDS. Miller suggests that a major contribution to firming notions about decentralized decision-making was from the Quaker tradition; he cites Hayden's association with Kenneth Boulding as a primary example. But Boulding is better known as a systems theorist: he was one of the four founders of general systems theory, and he devoted his career to combining his expertise in mathematical modeling with his radical nonviolence.

Boulding was influenced by Wiener's notions of social feedback in *Human Use of Human Beings,* but suggested that a balance between disruptive positive feedback and homeostatic negative feedback might be a better goal (Kerman 1974 pp 14-15). Boulding's work went beyond metaphor. His models were often supported by economic or other numeric data in specific historical context, and his politics were those of a "non-violent revolutionary." It is not surprising that Boulding is almost absent from Lilienfield's account. Wright (1989) reports that the Boulding house was a "nerve center of various protests" during the 1960s. Hayden was a frequent guest, as were other student radicals. Boulding's ideas were given a wider circulation through *Liberation,* a

widely read leftist periodical. Also appearing in this journal were essays by and about anarchist Paul Goodman.

Miller (pg 169) notes that Goodman's essays were an important influence on SDS theorists during the time that they were attempting to formulate a *Port Huron* sequel and break away from established liberalism. Earlier, he had published an essay subtitled "Speech as Action" - a concept which reconciles the ideal of "action now" with the reality of endless meetings - and Goodman's 1960 essay in *Liberation,* "The Face to Face Community," is a likely source for SDS use of this phrase. This essay mentions cybernetics directly only in critical irony: "there is today so much communication, means of communication, communication-theory that there isn't any community."

But Goodman was by no means an anti-technologue; in fact, his biographer Widmer (1980) accuses him of "idolatry of Western science." Here he refers to the essay "'Applied Science' and Superstition," in which Goodman proposed that science could be transformed from its current position as support for capitalist and military domination to a liberating practice if it could be put under humanist control. The critique centered around the need for decentralization of science as an institution, as illustrated by the decentralization concept within science, eg holistic health. It also highlighted the positivist obsession with a "Unified Language of Science," exemplified by "the present craze to program everything for computers." The result of the latter would be a generation of "symbol-manipulators, without feelings for the causes of things." It is this opposition to digital representation that he refers to in the denigration of "communication theory" in his "face to face" essay. Goodman often related his politics to the holistic scientific anarchism of Peter Kropotkin. His social commentary was also closely allied to gestalt psychology, and he eventually made direct ties to the cybernetics community through his interest in ecology and conversations with Gregory Bateson, who lived next door to him during his stay in Hawaii.

With the alignment between political features and cybernetic constructs, and the links through Boulding and Goodman, one might expect that SDS and associated student movements of the 60s were marked by a close association with science and information studies. Nothing of the sort happened: to student radicals, science itself was too digital, too much a part of the "military-industrial establishment." But holistic science advocates such as Goodman were not only read by *political* radicals of the 60s; they were also read, with much greater influence, by the *cultural* radicals of the time, the 60s "counter culture."

One of the definitive works on this period is Rosak's *Making of a Counter Culture*. He maps out the contours of this purple terrain through four areas: the "gestalt anarchism" of Goodman, the Freudian Marxism of Herbert Marcuse and Norman O. Brown, the Zen mysticism of Alan Watts, and the psychadelic "neuropolitics" of Timothy Leary. Rosak too dismisses science as both authoritarian repression of humanist recursion, and as alienation due to digital artifice:

> The technocracy rejects spontaneity, self-regulation... as if they were so much poison in the body politic, preferring instead goals and behavior that can be expressed in vast, abstract magnitudes (pg 198).

But the counter culture itself is much more intimate with cybernetics than Rosak is willing to admit. In the text he cites by Alan Watts (1961), for example, feedback oscillations, neural decentralization, and other cybernetic topics are frequent metaphors or even evidence for a playful (though orientalist) mysticism. In the preface, Watts notes "my increasing respect for the 'communication psychology' of Gregory Bateson and his associates... which goes hand in hand with my growing preference for discussing these matters in a language that is more scientific and less metaphysical."

The psychadelic subculture was even more embedded in science, having had the "Molecular Revolution" (Leary 1968) as its place of birth. Again, the concentration was

on the Wiener side of systems, on vibration, form and flux - but here a bit less natural, more "electrified." This was quite a point of contention for hipsters of "The Movement." Obviously, the world of digital linearity was for squares; but both acoustic and electric guitars were analog. In *The Electric Kool-Aid Acid Test* Tom Wolf describes a moment of the conflict:

> Somehow Norman got the idea that the people at Kesey's were like, you know, monks, novitiates, a lot of meditating with your legs crossed, chanting, eating rice, feeling vibrations, walking softly over the forest floor and thinking big.... But jesus, somehow it doesn't look very Tibetan.... tape recorders and pieces of tape recorders... plaited in among wires and sockets.... screaming Day-Glow tree trunks... mad stripes and swirls of orange, red green yellow.... (pg 138).

Although hippies had one foot in the natural chaos of their imagined primitivism, there was also a neon chaos vibrating with amplified distortion and artificial reverb. Marshall McLuhan, Buckminster Fuller and other popularizers used cybernetics to gloss over this gap; the utopian primitive and neon hipster would become one in the "electronic global village."

> It was... a considerable revelation when writing came to detribalize and to individualize man. ...Cybernation seems to be taking us out of the visual world of classified data back into the tribal world of integral patterns and corporate awareness (McLuhan 1966, pg 102).

Thus, McLuhan's slogan was the opposite of the analog/digital equivalence I have tried to promote. To McLuhan "the medium is the message," and by reviving the analog medium of our holistic past we escape the oppressive digital order of the present.

This politicized connection between cybernetic and cultural chaos was made particularly visible in the plastic and graphic arts of the 60s. In early Kinetic Art, and later Optical Art of the 1960s, there was a strong move towards material fluctuations, continuous shape distortions, modulated waveforms and other dynamic phenomena. Adams (1978) notes that this has been attributed to both social forces, "the ductility and instability of the changing world," as well as to scientific description of "the fluidity and ductility

of natural phenomena, intuitively incorporated into the language of art" (pg 57). Popper (1975) emphasizes the role of cybernetics in such "spatiodynamic" work (see figure 2.2). He cites a wide number of artists who directly or indirectly used both cybernetic technology and theory as the basis for their art. Franke (1973) notes that analog, rather than digital systems, were first used by technologically inclined artists, and that the figurative digital art we are used to today did not appear until 1967.

As in other areas, however, analog representation in art was not always looked on as representation; often it was promoted as the Real. Adams suggests that in Kinetic art the work "ceases to be a mere static depiction or evocation of reality *re-presented* by the conventions of art, but a re-enactment or actual aesthetic event happening before the viewer" (pg 58, italics in original). In an article on Lygia Clark, a founding member of the "Concretists" and later Kinetic art, Barrett (1967) states that Clark,

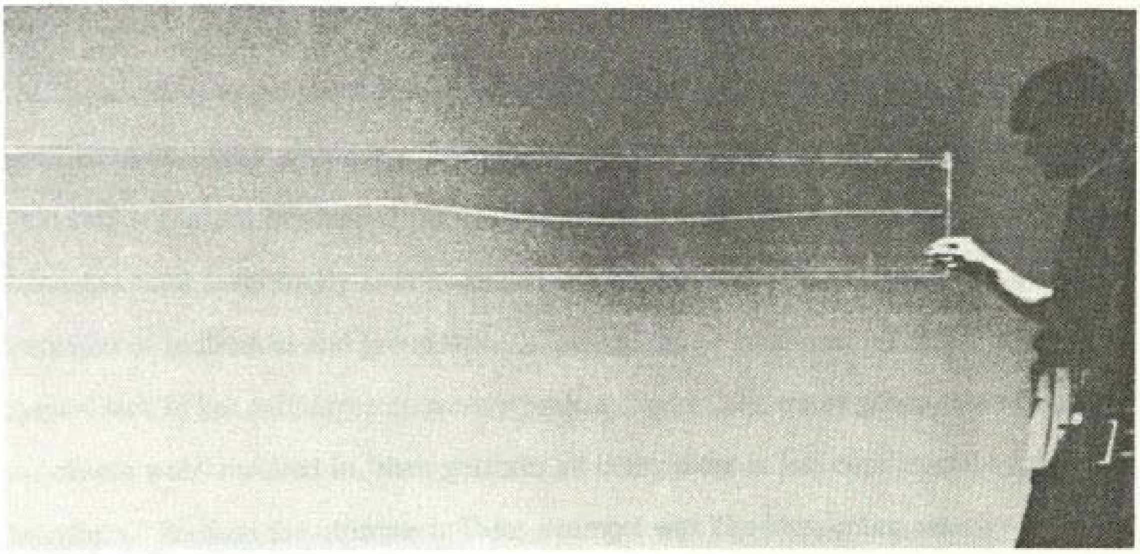
> in common with other kinetic artists, is in the direct line of descent from Cezanne, the Cubists and the Futurists. But, whereas they merely *represented* an object moving in space or as seen by someone moving round it, she and the other kinetic artists compose in actual space (pg 85, italics in original).

Clark is particularly important since she was one of the first to propose a move from analog systems to recursive, feedback systems; to works of art which the viewer helps to create. Barrett sees this move toward spectator participation as a natural consequence of analog dynamics. "The earliest kinetic works... did not call for a great effort on the part of the spectator.... But the more complex the movement becomes the greater the cooperation demanded from the spectator." Clark herself makes a similar connection in describing her robot-like "animals:"

> The animal has his own, well-defined cluster of movements which react to the promptings of the spectator. He is not made of isolated static forms which can be manipulated at random, as in a game; no, his parts are functionally related to each other, as is he were a living organism; and the movement of these parts are interlinked. ...The interlinking of the spectator's action and the "animal's" immediate answer is what forms this new relationship....

Figure 2.2: Art in the 1960s -- from analog representation to spectator participation

"McLuhan Caged" -- analog modulated video, by Nam June Paik. From Hultén 1968, pg 197.



"Large Wave" -- individual spectator participation by Hans Haacke. From Popper (1975) pg 101.

"Cellular Architecture" -- group spectator participation by Lygia Clark. From Popper (1975) pg 16.

Popper describes the ways in which cybernetics has directly influenced this promotion of spectator feedback. The most explicit example is from Roy Ascott: "Where art of the old order constituted a *deterministic vision,* so the art of our time tends towards the development of a *cybernetic vision,* in which feedback, dialogue and involvement in some creative interplay at deep levels of experience are paramount" (Ascott 1968 pg 136). Popper concludes that "Social and cultural involvement thus coincides with the emergence of a 'cybernetic vision', in art as well as science."

In addition to the problem of confusing analog representation with the Real, artists also had to deal with with the problems of recursive systems and hierarchy. If a work of art is self-organized in some sense, what is the role of the artist? Does self-organization at the spectator level imply artistic control at a higher level? Popper notes that this "problem of individual and group activity" was given an attempted reconciliation by Lygia Clark in her *cellular architecture* project (figure 2.2), where group assemblage of an "elastic web" resulted in "their gestures all being more or less conditioned by those of the others." Perhaps the ultimate in these attempts was The Happening, which was often extolled as open-ended, anarchic ritual. Yet even here, upper level control was evident: "Contrary to the public's conception, the majority of happenings are quite formal, are carefully rehearsed and do not invite any audience participation at all" (Al Hansen, quoted in Adams 1978, pg 75).

In conclusion: cybernetics had varying influences on different groups throughout the 1960s. Although the social concepts by these various groups appear similar - specifically the parallels between cybernetic self-reference and humanist self-control, and between cybernetic alternatives to digital representation and the organicist search for a more "authentic" medium - the actual connections to cybernetics, both practical and conceptual, were not consistently established. In the next section, we will consider some explanations for this variation.

2.5 Modern Cybernetics and Essentialist Politics

The last section described the 1960s in terms of four different sectors of U.S. society: Black activists, White activists, counter culture, and art. The order here is significant. It is (in a crude approximation) a gradient of economic level, moving from disenfranchised Blacks, to (mainly) working class identified Whites, to dissaffected middle class, and finally to professional class artists. Examined from this perspective, the reason why overt connections to cybernetics increased as we traveled along this gradient seems obvious: the poor have the least access to the academic and industrial resources of cybernetics, and the best reasons to mistrust a theory born out of military capitalism. True as this may be, I want to briefly consider a second explanation: that the modernist essentialism promoted by cybernetic politics was at odds with lower class perspectives, particularly for those articulated by people of color.

Among White student radicals and the SDS, the search for alternatives to hierarchy and formal representation was frequently proposed in terms of no structure and no representation; in terms of the Real or Authentic. When asked about the meaning of participatory democracy, SDS founder Sharon Jeffrey quoted the *Port Huron Statement:*

> The goal of man in society should be... finding a meaning of life that is authentic. I think authenticity is something that we were deeply committed to discovering within ourselves... but I could also connect it to black students... to the Third World (Miller 1987 pg 144).

Jeffrey joined in efforts to register Black voters in North Carolina in 1962. Here her search for authenticity led to some confirmations in physical dynamics.

"One of my best friends," she recalls, "was a black woman student. And one of the most profound experiences I had that summer was washing her hair -- *touching* black hair, and discovering it was soft" (Miller pg 186; italics in original).

For Jeffrey the physical structure of hair was the Real, not merely a representation. As a political activist myself, I can empathize with the feeling that experiential participation in

a struggle creates a special personal knowledge. But I also have a love for representations -- particularly that of hair.

Mercer (1988) discusses the meaning of "authentic" black hair in his critique of the recent controversy over Michael Jackson's curly-perm style. Condemming the notion that "hair styles which... look 'natural,' such as the Afro or Dreadlocks, are more authentically black hair-styles and thus more ideologically 'right-on,'" Mercer describes the ways in which the physical malleability of hair has been used to communicate the psychological malleability of black social identity. The conk of the 1940s for example, in which hot lye and special combs painfully transformed black kinks into straight red hair, was not an attempt to simulate whiteness (with its beauty norms of blonde hair in women and brown hair in men), but a method of defying conventional codes; it was the dandyism of exaggerated artifice. At the other extreme, he notes that dreadlocks would not seem particularly African in Africa today (they were used by the Mau-Mau to create an "alien appearance"), and both dreads and afros involve a great deal of hair styling tools and techniques.* It is a 'naturalism' of considerable construction. "We require a historical perspective on how many different strands - economic, political, psychological - have been woven into the rich and complex texture of our nappy hair, such that issues of style are so highly charged as sensitive questions about our very 'identity'" (pg 34).

While Jeffrey was finding a stable authenticity in the (supposed) identity of others, her own identity seems curiously up for grabs.

> "And one of the most profound experiences I had that summer was washing her hair - *touching* black hair, and discovering it was soft. Another profound experience was discovering anti-Semitism in the black community... They told

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*Mercer couches much of his analysis with the language of semiotics, but does not restrict himself to approaching different hair styles as different arbitrary symbols. He often describes analog relations, noting variations along semantic dimensions ("ranking on the ethnic scale"), as well as physical dimensions (dreadlock matting "with varying degrees of emphasis"), and he uses these to elucidate proportional relations between meaning and physical structure ("the larger the Afro, the greater the degree of black 'content' to one's consciousness").

> me about the 'Jew' who owned the stores... So I said, 'Well, you know, I'm Jewish.'" It was a lie. (Miller pg 186)

For white middle class students the line between an artificial Self and authentic Other seemed clear, and one needed only follow the path towards non-representation to cross this boundary. Touching Black hair was not a sensory representation of a cultural construction, but a direct line to The Real, a confirmation that the authenticity absent in white identity (which, after all, could shift from gentile to Jew without a hitch) could be found in Black physicality. This confirmation was less pleasant from the other side.

> I still have to deal with people who go to touch my "soft" or "loose" or "wavy" hair as if in the touching something... will be confirmed. Back then in the 60s it seems to me that my options... were to keep it short and thereby less visible, or to have the living curl dragged out of it (McClintock 1986, quoted in Mercer 1988, pg 53).

Having dealt with the problems of essentialism in much more direct ways than White radicals, and with more at stake (and a longer history) in problematizing authenticity, Black radicals were not as quick to seek romanticist appeals to the Real. Similarly, replacing hierarchy with a simple absence of structure was not as appealing in the Black political community. Since these were the dominant political interpretations of analog recursion in cybernetics, it seems reasonable to see this as an additional barrier to the use of modernist cybernetics in Black and working class political struggles.

2.6 The Death of Modernity; Birth of the Post-Modern era

By 1968 modernity came to (and passed) its dramatic crescendo - the French May rebellion, the death of King and Kennedy, the SDS decay into the Weathermen. It is significant that the two political movements rising out of this time - the revitalized women's movement and the lesbian/gay movement - both required a break with modernist naturalism to get their start. Neither the "natural role" of women nor the "unnatural sex" of lesbians and gays were legitimate political concerns for a counter-culture seeking

to purify its romantic psycho-ecology.

The rise of postmodern cultural and political theory is rarely attributed to such activist sources; a more typical origin story begins with the philosophical genealogies culminating in Jacques Derrida and Michel Foucault. While it is true that they both have very articulate (and sometimes overly articulate, to the point of obfuscation) accounts of this new analytic apparatus, it seems a bit ironic that a field so concerned with disrupting origin stories should support such stable origin stories for itself. This accusation of the lack of "reflexivity" (ie recursive critique, applying one's theory to oneself) is also a common trope in postmodern theory.

If we read works of fiction or even political actions as theory (see work by Noel Sturgeon of the History of Consciousness board on this approach), then the origins of postmodern analysis has a much broader and older basis. But even for more academic texts we see these ideas rise from more than one source. In the work of Foucault, for example, the humanist dependence on recursion is examined. He demonstrates that humanist goals of self-control, autonomy, and escape from centralized structure are not simply self-evident truths; they have been historically constructed as a part of social control. But a similar skepticism against decentralization as liberty was also voiced in the women's movement of the time - for example, in Joreen's (1972) "Tyranny of Structurelessness."*

In addition to the rejection of recursion in postmodern critiques of humanism, the organicist appeal to physicality as the Real was also contested. This was most explicitly carried out by Jacques Derrida, who used Rousseau's romantic account of the "authentic speech" of "primitives" to demonstrate the psychological repression underlying such claims for authenticity, and to establish the arbitrary signifier as the sole basis for human

*There are, of course, many centralist critiques of decentralization, but Joreen's text took a more complex angle of analysis. See Ehrlich 1979 for a critical view.

culture and consciousness.

While representation by symbols had been the central theme throughout most cultural studies disciplines -- particularly in anthropology -- there was always the question of this other mode of knowledge lurking in the background. Derrida showed that even for Lévi-Strauss, the central figure in the anthropology of symbolic structure, there were moments where he would see symbols as mere fakes, inferior due to their artificiality. Here Lévi-Strauss implied that the Real existed as a more natural, concrete mode of existence. Derrida countered this notion of the authentic by claiming that culture is "always already" symbolic, that even speech is still essentially symbolic since it too is writing (although writing on air rather than ink), that there is no original pre-representation but only the endless play of symbols.

I will return to Rousseau, Levi-Strauss and Derrida in detail in the discussion on acoustics in chapter 4. For now, it is sufficient to understand the basic ways in which Derrida's perspective compares to my own. Both of us agree that there are tremendous problems with the authority claimed by notions of the Real -- particularly that of Real Nature -- and that by seeing everything as representation we create the potential for a powerful liberatory space. Both of us reject the structuralist limitations on symbolic representation as a strictly ordered system, ultimately reflecting a unitary "author's intent;" and we both see text as nonlinear and pluri-dimensional, particularly in its self-referential depth. But for Derrida this means that only arbitrary symbols are capable of this full representation; anything I would consider an analog system is disregarded as a misguided invocation of the Real.

Just as Foucault's critique of recursion can also be read in other texts - texts which are often ignored because their source is that of a subjugated community -- Derrida's promotion of arbitrary signifiers and artificiality was not the sole voice for this position. Wittig's (1973) *Lesbian Body* takes a topic which was often treated as the unassailable

ground of feminist meaning, the authentic physical self, and dismantles this construction through a textual erotics. Like Derrida, she shows that a system of arbitrary symbols is just as capable of carrying the kind of human essence often attributed to the Real or Natural.

Of additional importance in Wittig's book is the association of this artificial, textual presence with White ethnic identity.* This connection has had powerful repercussions for postmodern theory -- at times closing off these analytic tools to those who need them most; but also bringing such ethnic possession into question. For example, some third world writers would insist that systems of arbitrary symbols are just as present in their culture as in those of Europe. Others would accuse them of selling out, and stick to a supposed authentic physicality. From my perspective the fight is somewhat unnecessary, since the non-symbolic physicality associated with non-whites (eg as described in the negritude movement) is also an artificial representation system, and no complex cultural activity can be reduced to one position on the analog-digital continuum. But it may have been a useful error since it forced these ownership issues. If analog representation *had* been used in this discourse, we might never have had such intense deconstruction of these White/Non-white dualities, and instead settled for an epistemological version of separate-but-equal. In addition this legitimation of artificiality mediated white guilt. It is impossible to liberate others if your own identity is supposed to be etched in evil; by making symbolic representation universal its use in oppositional practice could be realized.

*This was unintentional; her lesbian claims on ancient Greek culture were meant to be about a generic origin of civilization. Derrida only mentions the association as a romanticist error, but this may be due to his own ethnic identity as a North African Jew. The Jewish view of arbitrary symbols as universal (spiritual) knowledge or *ruhniut* is, of course, another ethnic association for this poststructuralist theory, and Spivak has listed several of Derrida's writings on this topic in her translation of *Grammatology* (pg 317). This connection is present elsewhere in the history of philosophy leading to poststructuralism.

In the 1960s American popular culture -- particularly youth subculture -- manifested the episteme of its age. Freedom, the utopic promise and its ethical norms, was expressed in terms of the autonomy of humanism -- escape from hierarchy -- and the authenticity of organic realism -- escape from digital representation. The transformation of these two polarities in postmodernism -- exposing the tyranny of self-control and abandoning appeals the Real -- also had their expression in the youth subculture of the 70s. While all aspects of cultural identity -- gender, sexuality, economic class, religion, etc. -- have had their interaction with both of these dimensions, the association of ethnic identity with analog-digital differences has been one of the most profound.

2.7 Ethnicity and the Analog-Digital Dichotomy in Postmodern Youth Subculture

> If you use the word 'postmodern' around here, none of these artists would know what you were talking about. They have no idea; this is just the way they've always done it.

-- Bill Adler, rap agency director (Dery 1988)

One of the problems with opening "theory" beyond the academy and into the universe of all cultural activity (besides never getting published) is the fuzziness of boundaries. Rap music is a case in point. Most of the writings on rap (eg Hager 1984, Toop 1984, Leland 1988) as well as the rappers themselves make a strong case for an extensive historical tradition: traditional African tribal music; the music of African-American slavery; jive, toasts and the dozens; and elements of blues, jazz and soul. How can postmodernism be historical if we find "it" at all points in history? What makes certain aspects of material culture or communication forms postmodern is not their inherent properties -- digital representation can be found in all complex cultural activities at all times -- but the ways in which they are manipulated as oppositional moves by subjugated communities or as domination by those in control.

As a group which often served the modernist era as an exemplar of analog society -- either the uncivilized primitives of the colonialists, or the organic nobility of the counter-culture -- Africans throughout the diaspora have had to take careful consideration of the analog-digital dichotomy. Previously I have used the Negritude movement as an example of a modernist approach to this dilemma. In the work of Léopold Senghor, for example, information embedded in physical dynamics -- analog representation -- is opposed to a characterization of The West in terms of arbitrary symbol systems. But other African writers have approached Negritude in a more complex way. Amié Césaire, who coined the term Negritude, has specifically rejected these essentialist tendencies (Clifford 1988). Mudimbe (1985) suggests that the fixation of Negritude into a "brilliant game of opposites" was largely due to White influence, as seen in Sartre's introduction to Senghor's *Black Orpheus*.

> To this career
> I did ordain
> Doin' things the anthropologists can't explain
> Arhythmic sounds
> Float like Lake Erie
> Altering any scientifical theory

- Sweet Tee, "On the Smooth Tip" *(Queens of Rap* 1988)

African-American urban youth movements of the postmodern era, often grouped under the term Hip-Hop, constitute yet another move in the analog-digital dualism game; but this time to the digital side. The term "digital" is itself used by these movements (best exemplified by the popular rap group "Digital Underground") to signify a guerilla cybernetics, both in terms of street-wise technical competence and in cultural communication forms.

Rap is notorious for its non-melodic sound: a disjoint collage of flat punctuated speech, spliced sound bytes from James Brown, *The Andy Griffith Show*, and video game lasers, and above all the scratch: deejays playing the normally silent back-cue of the

record in time to the beat, letting the raw signal of a misused stylus interface the acoustic codes into a single mutant form. Although not a commercial success until the Sugar Hill Gang's "Rapper's Delight" of 1979 and Grandmaster Flash's "The Message" of 1982, by 1977 most of these forms were already existing from low-tech necessity: budget disco parties without the money for a band or the passivity for records. Out of the pit of commercialized pop music -- the gold-chained discotheque scene of John Travolta and Studio 54 -- scratch turned tables on the turntables.

At the same time rap was cutting organic sounds into oppositional symbolics, breakdancing was digitizing the human body. Like rap, histories of breakdancing (DiLorenzo 1985, Hager 1984) cite traditions from African prehistory to contemporary African-American dance, in which discrete moves, rapid-fire symbolic gestures and percussive "popping" originated. Breakdancing also uses a stylistic collage of odd elements: "King Tut" friezes, Russian folk dance and street gymnastics are fused with the pro-artifice titles of "Electric Boogie," "Moonwalk" and "Robot." The android movements of Shields and Yarnell, a husband and wife performance team seen widely on popular television in 1977, were often incorporated by breakdancers in routines which code the machine-human interface in much stronger ambiguity than anything seen in the modern era. While an element of irony and parody are always present, there is also pride in the technical competence required to take on the cybernetic stronghold of industry, and a historical claim of ownership for these powerful modes of representation.

Finally, there is graffiti: not only a claim to ownership of coding, but coding as a claim to ownership. New York is the definitive center (although Philadelphia is a close second); the origin story here is unusually contemporary. In 1969 an unemployed 17-year-old started writing his nickname together with his street number on public spaces; soon Taki 183 was joined by hundreds of male and female writers of various ethnicities, genders and economic backgrounds. Since the majority are poor, the activity is often

interpreted as a rebellion against their economic trap: a signature marks possession.

Castleman (1982), in a solidly ethnographic study of of New York graffiti writers, balks at such interpretations -- not necessarily because they are incorrect, but because it is all too easy to read these meanings into their work rather than seeking a thick description of their lives and activities. What stands out in his account is the assertion of identity, both as individuals and as members of the writer's community (gangs, groups, organizations and the city as a whole). While the digital aspects of the graffiti -- the sequence of symbols -- tended toward literal identification (eg Barbara and Eva 62), the analog aspects -- the style in which the letters are written -- were sites of various cultural tensions. Style means "making your name sing" (pg 53), and style wars alternate with cooperative revolutions. The style variations reflect manipulations of media technology (eg substituting wide dispersion spray starch tops for the narrow paint tops), ethnicity, and a wide range of personal attitudes, ideas and affiliations.

The distinction between analog and digital here is quite dynamic, and also reflects these cultural meanings. Bubble letters, for example, were started by a writer named Phase II, and the waveforms named "bubble cloud," "stretch bubble," "bubble drip," "squish luscious," and "spiral-gyro-tasmarific" attested to his ability for an accelerating elasticity of letter shape. But style borrowing ("biting") is looked down on (sometimes violently), and the analog variation within a style is frozen into digital distinctions between styles. Like rap and breakdancing, graffiti carries a positive affirmation of the artificial - urban life is celebrated, and many styles are tight geometric forms titled "computer," "mechanical," "robot," etc. - along with the irony and parody that keeps their sentiments accountable to the brutalities the technology carries.

All three of these aspects of hip-hop include many examples of analog communication, but all three emphasize the digital representations in ways which make the movement as a whole far more friendly to artificial states of being: to urban life, machines,

science, and even to artificial origins.

> Post-liberated black hair-styling emphasizes a 'pick n' mix' approach to aesthetic production, suggesting a different attitude to the past in its reckoning with modernity. The philly-cut on the hip-hop/go-go scene etches diagonalized lines across the head, refashioning a style from the 1940s where a parting would be shaved into the hair (Mercer pg 51).

While I strongly disagree with the standard semiotics claim - that only arbitrary symbols allow the kind of collage effect which forms the basis for these unnatural combinations - I think the way in which the use of arbitrary symbols *signify* artificiality is a crucial part of this postmodern distinction. The New York graffiti painters may be analog artists in many ways, but their preference for the term "writer" reflects their own textual emphasis. In the modern discussions of African music the emphasis on percussion was always a demonstration of the analog character of Africans (either as "natural rhythm" ascribed by racists or the cultural talent claimed by Negritude), but in postmodern descriptions of hip-hop it becomes proof of Africa's digitality. Here artificiality, given by the metasignifier of digital representation, becomes a 'natural' tradition, and it is in this kind of paradox that the postmodern transition achieves its strongest potential for upsetting the dualities themselves rather than merely reversing their content.

While African-American, Latino, and other non-white youth were remixing their cultural codes, White youth also found a new energy in inorganic urban existence.* Hebdige (1979) examined this history in one of the first postmodern analyses of youth subculture. His analysis is centered on the British punk scene, which he contrasts to the early skinhead movement and an emerging Rastafarianism in Black British culture. Both the skinhead and Rasta youth cultures drew their identity from a natural utopian past. For the skins it was a "lost" working class community: they dressed "as a kind of caricature

*Here my emphasis on ethnicity gives way to the lie such single dimension analyses must produce. The hip-hop scene contained significant numbers of poor white youth - or at least Castleman reports this - and similar exclusions/inclusions on the basis of gender, sexual identity, etc. are crucial to the form these activities take.

of the model worker: cropped hair, braces, short wide levi jeans... and highly polished Doc Marten boots" (pg 55). In Black communities many previously "soul" youth "began to cultivate a more obviously African 'natural' image... the pork-pie hat disappeared to be replaced by the roughly woven tam... tonic, mohair and terylene - the raw material for all those shiny suits in midnight and electric blue - were exchanged for cotton, wool and denim" (pg 43). Despite the skinhead's eventual concentration on racial bigotry (an attack on immigrants in 1972 was the crucial turning point), Hebdige makes a good case for their use of the African redemption themes as a model for working class redemption.

The punk origin story resembles that of rap, with Glamour Rock (eg David Bowie) taking the place of Disco. The commercialized artificiality of Glam, focused on a decadent androgynous elite, gave way to the decadent androgynous (or at least perverted) street sounds of Punk. In 1977 - at the all-time high of teenage suicide in the U.S. - the Sex Pistols' *Never Mind the Bullocks* sounded a call to arms for a generation unimpressed by their parent's claims for a peace and love revolution.

Despite some clinging to modernity (their song "Bodies" is an anti-abortion screed) the Sex Pistols set the style for what Hebdige calls a "nihilist aesthetic." James (1984) refers to punk as "the final modernist capitulation to decadence, irrationality, and despair." I prefer, for obvious reasons, to concentrate more on punk's postmodern aspects. Hebdige suggests that punk expressed a white ethnicity, but one which was bound to present time rather than the skinhead's utopic past. Rather than a modernist despair over alienation, punk affirms alienation as a part of its ethnic identity, parodying the sympathetic beneficence of liberal sociologists.

Having built its identity as a deliberate construction, an ethnicity of artificiality (and a similar analysis might be made for sex/gender, eg The New York Dolls), punk insists on a self-accountability which, unfortunately, often goes no further than nihilism. But this nihilism is too often interpreted as the entire meaning, rather than simply one

possible consequence. For example, in his analysis of the punk use of swastikas, Hebdige notes that the punks had no sympathy with fascism (and in fact were powerful components in several leftist actions, most importantly in the Rock against Rascism campaign), and concludes that "we must resort, then, to the most obvious of explanations - that the swastika was worn because it was guaranteed to shock" (pg 116). In conversations I've had with punks (and with other Jews who were, far more than myself, punk participants), I found two sentiments expressed by their use of this symbol. First, there was a simultaneous refusal to deny a "contaminated" ethnic heritage, and a refusal to feel shame or guilt over this contamination. Punks will never apologize for their white identity, nor try to mask its negative associations. Second, there was an insistence on the arbitrariness of symbols: "don't force *your* meaning on my symbol, I can make it mean whatever I want."

Indeed, the arbitrariness of symbols and symbolic arrays is essential to all punk material culture. The clothing is a an urban screech of plastic and metal; the hair a neon dyed, machine sculpted artifact; the make-up flaunts the taboos of all fashion advice; and the music itself is an unrelenting succession of noise. Despite the frequent use of the term "chaos" to describe punk (eg Jonny Rotten's famous line "we're not into music, we're into chaos"), the punk aesthetic bears no resemblance to the hippy use of natural flowing chaos, to patterned organic shapes which opposed the establishment's Euclidian order. The disorder of punk is 'white noise,' the randomness of disrupted syntax, "a place where the social code is destroyed and renewed" (Kristeva, 1975). The songs of the Minute Men are all under 60 seconds, the Circle Jerks's songs not only standardized in time, but repeat the same chord pattern as well. Just as Rap uses speech to break up the organic flow of music, punk interjects order where it does not belong. In hippy culture plastic meant the establishment's order (as in "plastic hippy," or Dustin Hoffman's economic advice in *The Graduate)*. To punks plastic is "plastic" in the sense of

transformable; its excesses could force the system against itself, drowning institutional order in the noise of its own symbolics.

> Interviewer: What about that swastika you wear?
> Punk: Like I'm not going to go out and kill some Jew. C'mon -- Maybe a hippie.
>
> ~ from *The Decline of Western Civilization* (documentary film by Penelope Spheeris)

If punk is so intent on self-defined symbolics, doesn't that mean they subscribe to a modernist program of recursive control or humanist self-definition? Far from it. In terms of individuals, humanism differentiates between control from false authority and control from the true, authentic self. With no interest in authenticity or the "true self," Punks promote fakes as the only legitimate sincerity. In terms of collective activity, the same disruption occurs. Chambers (1985) describes this for punk efforts to subvert the recording industry.

> Punk's rough populism, what it would call... 'street level' music, was frequently translated into a flood of small, independent record labels. These apparently mushroomed around the subculture's early leitmotif: musical populism + recording independence = cultural autonomy. But as the idea of 'authencity' (hence the measure of 'autonomy') was also a rather non-punk concept, the whole formula remained precarious. Both punk and these recording initiatives ended up finding their own contradictory spaces within existing commercial categories. But in the process they produced an important series of fractures across the music, the music industry, and in musical journalism and criticism (pg 228).

In contrast to the 60s counter-culture's search for recursive control, the postmodern youth culture fought for a critique of this humanist self-reference. Just as the paradox of Rap's natural artifice opened a space for new cultural constructions, punk's recursive critique of recursion provided another opportunity for creating new kinds of resistance.

There is nothing particularly original in my claim for a postmodern episteme in youth culture: Chambers summarizes rap and punk as "musical deconstructionists," and the foundational texts of postmodernism have used the blurring of the pop culture/high

culture line as a defining concept. If anything, I am concerned that the move is made too easily. Its one thing for a ghetto youth to rip off high art, and quite another for wealthy white commercial artists to pat themselves on the back for their glib use of the ghetto - and the postmodernity which makes the first possible also prevents any distinction between the first and the second.* The main purpose of my portrait of youth subculture here is to make a claim about the cultural meanings carried by different types of representation. I am not so much imposing cybernetic categories on social description as I am explicating the social implications of cybernetic categories. Just as the counter-culture of the 1960s co-evolved with cybernetics, defining itself as the cybernetic opposite of digital hierarchy (in parallel with the military, industrial and institutional move to define itself as the cybernetic opposite of analog decentralization), the affirmation of digital representation and scepticism about recursive control in postmodern youth subcultures occurred in tandem with a scientific revolution in the opposite direction. Postmodern cybernetics requires analog recursion; it is here that science seeks chaos.

2.8 From Modern to Postmodern in the Information Sciences.

As a way of mapping the transition to postmodern cybernetics, this section will follow information systems as expressed in four different scientific disciplines: in mathematics, machine intelligence, visual neurobiology, and cerebral lateralization. In all four areas, we see a similar transition: the emphasis changed from digital to analog and from linear hierarchy to non-linear decentralization.

In the mathematics of the 1960s, research support concentrated in symbolic logic, linear programming theory, and other areas suited for digital analysis. Research in non-linear systems continued as it had for the last century; an interesting but predominantly

*Nor would I support some kind of essentialism in which the distinction was forcefully determined.

intractable area of inquiry. Complex systems were best approached in terms of complex linear elements. In a recent interview, Joseph Ford recalled his early attempts to introduce notions of complex nonlinear behavior in a lecture on the Duffing equation.

> When I said that? Jee-sus Christ, the audience began to bounce up and down. It was "My daddy played with the Duffing equation, and my granddaddy played with the Duffing equation, and nobody seen anything like what you're talking about." You would really run across resistance to the notion.... What I didn't understand was the hostility. (Gleick 1987 pg 305).

The hostility to nonlinear problems was not some quirk of individual psychology; it reflected the cultural associations for these analog feedback loops. When the NSF withdrew Steve Smale's mathematics grant, it was neither due only to his political affiliation or his nonlinear mathematics, but to the perception of danger in their combination. [more on this - Ralph just received an autobiographical article by Smale]

The earliest machine information systems involved in this transition to postmodernity were the automatic machine tools. Noble (1979) describes the replacement of the original analog design (a magnetic tape "record-playback" system developed in 1947) with a digital design (the "numerical control" system), which became ubiquitous by the 1960s. Through a variety of sources - interviews with the original engineers and managers, union records, and ergonomics studies, Noble demonstrates that the digital system was preferred because it appeared to maintain managerial, rather than machinist or shop-floor control, over the production process. Just as the analog dynamics of Lygia Clark's art work seemed to lend itself to spectator participation, there seemed to be a recursive component to analog representation in machine control. This association of these two independent dimensions has no objective or inherent basis; recursion was linked to analog representation due to cultural associations about 'natural labor'. As the consulting engineer at GE put it: "with numerical control there is no need to get your hands dirty" (Noble 1979, pg 33).

As in the case of automatic machine tools, the early automatic "thinking" devices were at first explored on a flat, unpolarized map where analog and digital, recursive and non-recursive all seemed equally attractive. For example, in a 1953 research project comparing analog and digital computers, Rubinoff (from the US Office of Naval Research) concluded that "a choice between analogue and digital simulation is not clear cut" (pg 1262). By the 1960s research resources were primarily directed towards the hierarchical von Neumann hardware and similarly structured software. The decentralized hardware approach received its fatal blow from Minsky and Papert's (1968) text on "perceptrons," in which they proved that these neuromimetic systems were incapable of solving certain significant classes of recognition problems. Dreyfus and Dreyfus (1988) have argued that Minsky and Papert intentionally blocked research on decentralized systems, a suggestion supported by Minsky and Papert's own declaration that they had a "therapeutic compulsion" to "dispel what we feared to be the first shadows of a 'holistic' or 'Gestalt' misconception that would threaten to haunt the fields of engineering and artificial intelligence" (quoted in Pollack 1988, pg 360).

The software conflict was much less competitive. While recursive programming had been know since Lovelace, it was never seriously proposed as the global structure for a machine intelligence system. Recursion was part of the theory leading up to computers, and its role as a workhorse of AI in the language LISP was appreciated. But the notion of decentralized control in AI programming was not seriously considered in the 1960s; rather the problems were thought to be in proper construction of a linear hierarchy (cf Pylyshyn 1981).

Models of information processing in the visual cortex have held a star position in the analysis of natural systems; partly due to the ease with which digital computers could approach (although not solve) language tasks and the absence of complex language in animals. While visual processing models in the 1940s and 50s included a wide variety of

schemes, in the 1960s these were all over shadowed by the discrete hierarchy model of Hubel and Wiesel (1962). In their scheme the lowest layer of cortical cells respond best to the image of a line, with different cells specialized for a particular width, slant, orientation and place in the visual field. Cells of the next layer up can distinguish between long lines and short lines, and cells of the next layer up require more complex stimuli (eg corners) to respond.

The hierarchy of this neural model is strikingly similar to AI models of the time: lower level "feature extraction" breaks the scene into elements which higher level functions categorize, creating the new elements for processing by the next level up. It was also (in contrast to AI) empirically well supported, with the "autoradiograph" seeming to allow the neurons to speak for themselves.

Research in cerebral lateralization has been featured in several essays on social studies of science. For biological determinists the dualism seems all too clear; for their critics it is all too convenient. Star (1979) noted the double mapping of both ethnicity and gender, pointing to Ornstein's (1973) popular book on brain asymmetry and its use of both East/West and female/male stereotypes. Here, it is insinuated (although never explicitly claimed) that the holistic right hemisphere is the female, Eastern side; and the reductionistic left hemisphere is its male Western counterpart. The association is not necessarily with malice, however. For example, Star quotes from a radical feminist journal:

> So dualism resides in the very brain. The ways of perceiving that came to be grouped in the left hemisphere are the tools men used to take control of the planet. Linear thinking, focused narrowly enough to squeeze out human or emotional considerations, enabled men to kill... with free consciences (pg 71 in Star).

Even in the professional literature, the association of gender and hemisphere has been suggested from this view of a positive social critique. Bogen (1969) defends the

right hemisphere as unjustly disparaged, and suggests that since these same attributes (intuitive, gestalt perception) are attributed to women, the belittlement has a sexist bias.

The institutionalization of digital hierarchy models in all of these areas, from machine tools to neurobiology, rose with its opposite in the 60s counter-culture; 1967 - the summer of love - was also a peak for cybernetic order. By 1977 this had reversed. In the same year that the Sex Pistols declared their love for the sharp euclidian lines of urban artificiality, cybernetic models flipped to the natural holistic flow of chaos.

Of course, chaos theory itself is the clearest example of this transition. Fractal geometry, dynamical systems theory, cellular automata, and other models of self-organizing process created a dramatic acceleration in the ability of scientists to study the recursive flow of information which underlies a wide variety of complex nonlinear phenomena. In the next chapter, I will describe the history of this interdisciplinary collection of mathematical models from premodern to postmodern eras. For now, it is sufficient to note that chaos theory reverses the emphasis of mathematics in the 1960s: it concentrates on the complex information that occurs in physical dynamics -- specifically nonlinear systems -- and describes this relation in terms of recursive structure.

In machine intelligence both hardware and software went through a sudden transition toward Minsky's threatening shadow of holism. In hardware this had at least three separate branches.

In the digital parallel processing approach, many von Neumann-type (ie sequential) processors are linked together, working on different parts of the problem at the same time. The problem can be divided up in different ways with varying degrees of autonomy; at their most extreme decentralization we return to the perceptron. It turned out that Minsky and Papert's analysis did not take into account the possibility of perceptrons linked in groups of three; this minor addition resolves the pattern recognition limitations

they had raised (Pollack 1989).

In the simulated annealing approach (cf Kirkpatrick et al 1983), an optimal state for an information system is approached by allowing carefully controlled randomness to perturb local elements, tossing them into desired configurations (i.e., "hill-climbing" to local maxima) and then decreasing the randomness before they are tossed out. This method makes use of the digital simulation of a physical process (thermal control of annealing in metals).

The holistic extreme for hardware was the coupled oscillator approach (cf Hopfield 1982) where computation was carried out by decentralized networks of analog units modeled on neurons.

The software decentralization in machine intelligence research was first utilized in the language ABSET (Elcock, McGregor and Murray 1971), which allowed data-directed control. More explicit decentralization was achieved in the "actor" formalism of the work of Hewett (1977) and the knowledge representation system of Bobrow and Winograd (1977). The most famous discussion of this research is Douglas Hofstadter's (1979) *Gödel, Escher, Bach;* a fantastic mix of hacker culture icons (the list of which now includes *Gödel, Escher, Bach)* with a manifesto for heterarchy, randomness and decentralization in AI programming. Hofstadter is responsible for bringing the issue of recursion into focus for a wide interdisciplinary audience.

Digital recursion in machine tools was also introduced at this time. Noble notes that the next generation of automatic machine tools, Computer Numerical Control systems, "reintroduces the record-playback concept in an updated digital form" (pg 46).

In visual neurobiology the challenge to Hubel and Weisel's work began with Campbell and Robinson (1968), in which suggestive evidence was presented for global frequency functions in the striate cortex. For example, one experiment showed a neuron

which fired optimally for an image of a monkey's hand: a specificity which is too great for Hubel and Weisel's model, but fits well with the global frequency model since the monkey's fingers form a spatial grating. However, it was not until DeValois et al (1978) that "critical" experiments which purported to decide the issue actually challenged the dominance of local feature extraction models.

As in visual neurobiology, changes in cerebral lateralization models were presented as compelling objective data requiring a different conceptual frame, not as a more sensible or fashionable theory. Once researchers had settled on a postmodern reversal - assigning the digital left hemisphere to women and the right hemisphere to men - a multidisciplinary complex of theoretical apparatus was quickly assembled. Levy (1978) developed an origin story in which "man the hunter" needed the gestalt skills of mapping and spear tossing while "woman the gatherer and childrearer" needed her social communication skills. While Buffery and Gray (1972, quoted in Star pg 68) suggested that female superiority in symbolic systems corresponded with "good performance on clerical tasks," Geschwind (reported in Kolata 1983) linked a supposed innate mathematical superiority in males to testosterone effects in fetal brain development, which would then produce "superior right hemisphere talents, such as artistic, musical, or mathematical talent" (pg 1312). Note that mathematics in this description has moved from its 60s association with the symbolic left hemisphere to a postmodern association with the analog right hemisphere.

2.9 Conclusion

Obviously, this disciplinarily widespread and temporally concentrated coupling between science and popular culture is a case for the social construction of science, and for science itself as a social or cultural process. It is particularly valuable for the kind of circularity highlighted by Latour and Woolgar (1979). For example, the constructivist

descriptions of cerebral lateralization (eg, Alper 1985, Star 1979) emphasize that not only is the cultural attribute of gender constructed, but that the biological "fact" of sex is also fabricated from the social matrix. Thus lateralization research is portrayed as one move in a circuit, which first inscribes cultural dualities into biology, and later promotes them as discoveries which explain the "natural" origin of social dichotomies.

The empty victory of female control over a devalued hemisphere brings some similar moves in ethnicity into question. In Dery's (1988) excellent article on rap, he writes about the digital tradition in Africa in relation to its languages: "the hums, grunts, and glottal attacks of central Africa's pygmies, the tongue clicks, throat gurgles, and suction stops of the Bushmen of the Kalahari Desert... all survive in the mouth percussion of "human beatbox" rappers..." (pg 34). As memory this is fine, but if interpreted to suggest that African languages are somehow *more digital* than others, it implies a reverse Rousseauism -- in the context of a supposed innate superiority of the right hemisphere, an up-side-down Derridian nightmare.

Not only do the postmodern reversals make oppositional moves more difficult to gage, they also make it difficult to understand domination. One of the first proclamations of this transition was Capra's (1975) *Tao of Physics,* which claimed that an ethically superior "Eastern" or holistic view was implied by theories of subatomic particles. For Roszak, subatomic physics was a symbol for the reductionist repression of technocracy: "one should avoid talking about one's "inner" feelings and look at the world in the way... a physicist views the behavior of subatomic particles" (pg 53).

Soon following Capra's work, popular views of postmodern cybernetics waxed ecstatic; Toffler's (1980) *The Third Wave* and Ferguson's (1979) *Aquarian Conspiricy* were two of the worst offenders. Correctly noting the moves away from centralization and digital formalization in postmodern industry and institutions, they conclude that this means a move toward the utopia which these polarizations promised in the 1960s.

Unfortunately, many of their critics (cf the collection in Slack and Fejes 1987) stick to a modernist analysis, attempting to show that these moves toward recursion and analog systems are not really happening, or are restricted to technical spheres which remain separate from political concerns. But the connection is obviously at work on the science side. For example, in explaining decentralization in AI software, Pylyshyn (1981) declares that "this means loosening the hierarchical authority relation common to most programs, and distributing authority in a more democratic manner, allowing for 'local initiative'" (pg 79). Pollack notes that although the new, revised edition of *Perceptrons* continues to critique the decentralized hardware approach (and this time, he suggests, with malice), Minsky's (1986) popular new text *Society of Mind* proclaims that he was thinking about decentralization in software all along, and now is willing to reveal his grand unified theory for decentralized AI programming.

Why is it that the "threatening shadow of holism" is no longer threatening to Minsky? That female and non-white control of symbolics is less repressed? And why, in particular, would the industrial managers of Noble's study be willing to allow self-control on the shop floor? Even the high level holism of industry and institutions envisioned by Toffler and Ferguson is occurring; a modernist critique denying this transition cannot be effective in seeking new forms of oppositional analysis or action.

The critique of "control through order" was the product of careful study by Mills, Kaufman, and other modern scholars. Developing a critique for the cybernetics of chaos will require the tools of postmodern scholars. The next chapter sets out some of this critique, starting with chaos in the premodern era.

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Chapter 3: A Short History of Chaos

premodern past to postmodern future

3.1 Overview

Chapter two portrayed the transition from modern to postmodern cybernetics in terms of a technical reversal from order to chaos - from digital hierarchy to analog decentralization - and an accompanying reversal of institutional power, that is, from attempts to control society through formal reification and imposed order to control through informal dynamics and self-management. In tandem with this transformation, we also see an opposite reversal in youth subculture, from the natural chaotic flow of the hippies to the sharp Euclidian artificialities of punk and hip-hop.

This chapter will examine the history of these dualities into the late 1980s. In this time period the technological communities and those of youth subcultures continue their odd linkage, but here in terms of a synthesis of the opposites, of chaos and order combined. This synthesis tends to stabilize some of the abrupt changes that occurred during the initial postmodern period. It is a stability which I find to be politically suspect.

Since chaos - both mathematical and cultural - is at the center of this transformation, it will be helpful to have a wider understanding of chaos history before beginning this analysis. The first section of this chapter will look at the premodern origins of chaos mathematics, and the role played by social conditions of modernity in its suppression.

3.2 Chaos in the Premodern Era: the necessity of nostalgia

Advocates of the ethical holism stance often use the premodern/modern transition as historical evidence. Merchant's *The Death of Nature* is a widely read classic of this genre, and is both readable and impressively erudite. She presents the rise of Western

science as an ethical downfall, due to an assertion of reductionist ("mechanistic") perspectives over a previously holistic ("organismic") world view. Her well researched and documented study does indeed provide accurate examples of this putative relation -- particularly in the comparison between a progressive subordination of women and an increasing exploitation of the environment (both seen as having a "wild and uncontrollable nature that could render... general chaos") -- but the commitment to notions of the ethical superiority of holism cause her to overlook possible contradictions. For example, she cites Rene Descartes as a key figure in providing the epistemological foundations for mechanistic misogyny. But as Grimshaw (1986) notes:

> Descartes' belief that there was a distinctive method of reasoning which, if followed by any human being, would guarantee the discovery of truth, was in many ways egalitarian in intent. Descartes had no intention of excluding women (and one of his main philosophical correspondents was a woman). He wrote in the vernacular, not in Latin, which was in itself a way of expressing a belief that arriving at the truth did not depend on following the institutional procedures of the medieval schools, from which, of course, women had been excluded. And it is not easy to see an ideal of masculinity or femininity as written into Descartes' theory of knowledge in the way I have suggested it is in [Kant and Aristotle]. (pg 53)

A fuller portrait of natural/artificial dichotomies in the premodern era can be found in Frykman and Löfgren's (1987) *Culture Builders*. Their historical ethnography of the Swedish bourgeoisie, concentrating on the Oscarian era from 1880 -1910, describes middle class efforts to differentiate themselves from what they saw as the natural primitivism of peasants and the degenerate "overcivilization" of the aristocracy. The middle class represented itself as a balance between disciplined, analytic rationality and sensitive, purifying love of Nature.

This effort by the rising middle-class to construct itself occurred at every level of social life, from home decor and vacation plans to hospitals and education. Perhaps the most important aspect, however, was the Oscarian era creation of folklore studies and internal histories. From Frykman and Löfgren's view, when we read a Swedish history

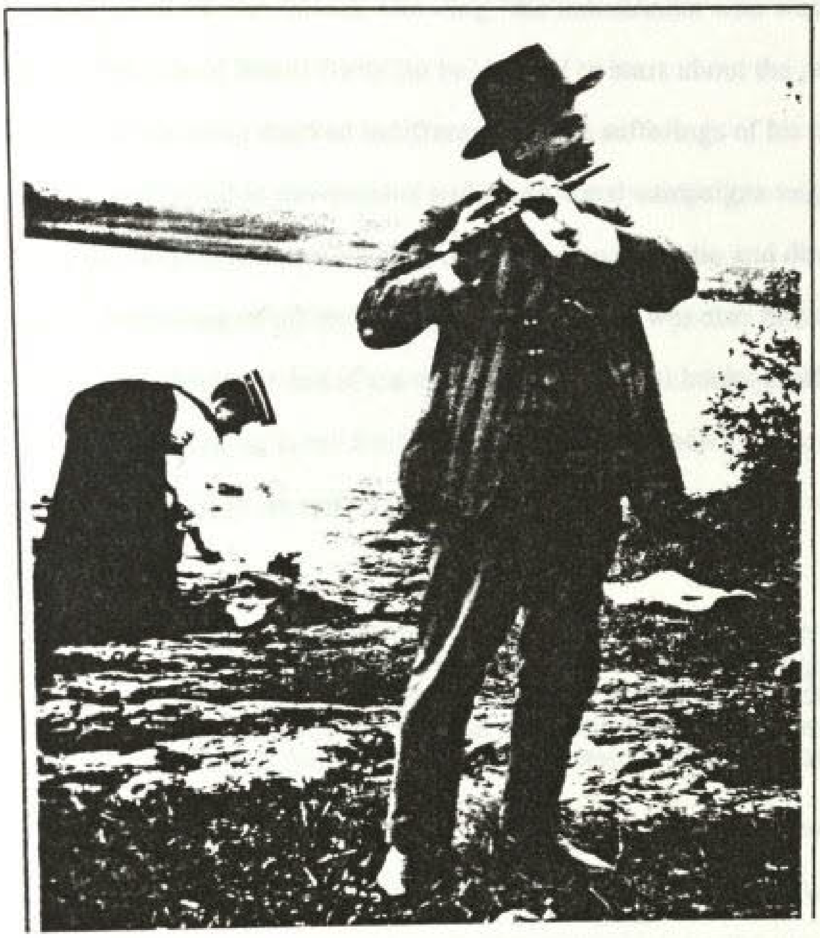
of how premodern peasants lived in an eco-holistic utopia, we are not so much learning about peasant life as we are about middle-class desire, nostalgia, and self-construction through the mirrored creation of a reversed "other."

This is nicely illustrated by Swedish folklore studies on peasant views of nature. For example, there was a great interest in peasant sayings "from the time when animals... could speak," such as the cow's advice that "Sallow leaves fatten me, aspen leaves feed me, rowan leaves starve me, alder leaves flatten me" (pg 46). To the 19th century folklorists this was proof of animistic religious beliefs, of a unity between people, spirit and nature. But Frykman and Löfgren point out that such rhymes were developed for children's education, and present evidence that this pedagogical device was part of a complex system of rational, analytic ecological classification which framed nature as a sphere of production.

The genesis of a Romantic or organicist attitude in the Oscarian middle class not only made use of an imagined peasant primitivism, but also constructed Nature itself as a source of moral purity and redemption (fig 3.1). As "the agricultural landscape was rearranged in geometrical patterns" for the new modern farming techniques, the non-geometrical chaos of untouched Nature became a crucial image for the bourgeoise. Touring clubs and guidebooks proliferated, oil portraits of rugged landscapes became ubiquitous, and with mass-production technology the scenic postcard was born. Thus Merchant's observation of scientific rejection of holistic, "natural" chaos has some truth, but science also helped to *produce* this conception of Nature (along with its metonymic population of primitives and females) as more holistic, and valorized this primitive chaos -- as long as it kept its place.

It was extremely important that this uncontaminated chaos maintain its proper position in nature. The working-class was seen as a perversion of this boundary, a place where the natural and artificial mixed in uncontrolled profanity. "There were too many

Figure 3.1: Redemption in nature



From Frykman and O. Löfgren (1987), pg 11.

noisy voices and boisterous picnics with accordions, beer, and card playing, and far too little of that aesthetic asceticism which middle-class nature lovers regarded as the proper mode of conduct in the sacred halls of nature" (pg 72). This class warfare was not lacking in retaliation, and the bourgeoise was heavily armed.

Societies for prevention of cruelty to animals framed moral accusations concerning the insensitivity of the lower classes, allowing "the industrialist who was a member of the Society for the Friends of Small Birds [to be] moved to tears about the problems of the little thrush, while showing marked indifference to the sufferings of his own workers" (pg 85). Oscarian charitable movements and educational campaigns taught that "the workers lived like animals, that the world of poverty was chaotic and dirty," and that "disorder is the beginning of all sin" (pp 219, 244). Order was also threatened by uncontrolled sexuality, particularly that of masturbation. "Medical books proffered concrete advice to parents concerning cures for the habit, from diets, water baths, and medicine to more drastic measures such as spiked cages and plaster casts" (pg 241). As Frykman and Löfgren conclude,

> The same zeal for order is seen in the organization of public life, in the straight rows of hospital beds and school desks, in the symmetry of the engine room and the old people's homes. All these seemingly unimportant details are part of the constant struggle against the threat from chaos and from those who live in chaos: the others, the uncivilized masses, the animal-like workers.

While the Oscarian workers were seen as a source of dangerous chaos, confusing the boundaries of nature and culture, the aristocracy was profiled as "over-civilized," plagued by the "pretentious rituals and empty etiquette" of an "artificial and petrified life-style" (pg 267). As the bourgeois definitions of proper civilization became dominant, even the aristocracy began to mimic them. But fanatic house cleaning was not an option for the nobility, and their search for rational order had to take place at a grand scale. It was for this reason that King Oscar himself decided to set the heavens in order.

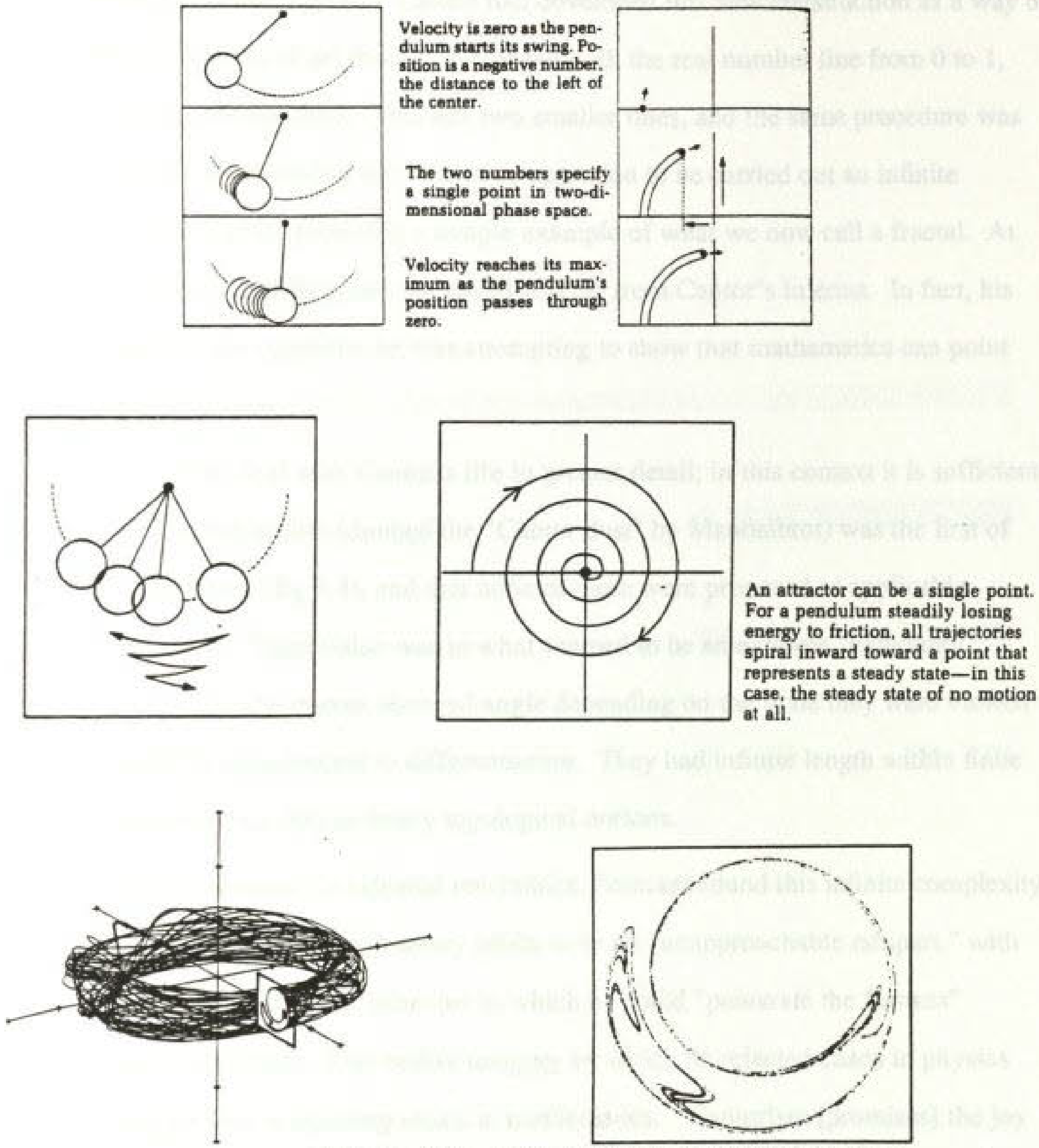
A long-time fan of mathematics, Oscar II learned that mathematical models of the solar system had yet to demonstrate the long-term stability of the planets. While the mundane nature of earth might have a pleasant chaos in its raw, untouched corners, heavenly nature would, of course, show its more spiritual side of order. The task was not easy however, and in 1887 he announced an international contest, with 2,500 crowns going to the mathematician who could produce equations allowing complete prediction of all planetary motion. Like most attempts at total purity -- like the homemaker who doubles the cleaning effort only to find twice the dirt -- this project was self-defeating. Oscar's award went to Henri Poincaré, who proved the impossibility of long-term prediction due to chaos.

The problem of predicting the motion of two bodies in gravitational attraction had been solved by Newton much earlier, but extending this to more than two was a tremendous leap in complexity. Poincaré's insight into the problem hinged on his realization that he did not have to map out the entire space of all possible states. Instead, he could take a slice of this phase space (now called a *Poincaré section)* and see if any of the points of this slice were crossed again by later trajectories (fig 3.2). If so, then the system would have returned to the same state, meaning that no matter how complex its behavior it would continue to repeat this behavior forever. In addition to this periodic solution, it was also possible that all behavior would contract into one phase space point (eg if the planets fell into the sun) or expand off to infinity (eg if the planets went flying away from the sun).

Poincaré was unprepared, however, for a fourth possibility. The trace of points inscribed on the surface of his slice never stopped changing, nor did it go out of bounds.

> These intersections form a kind of net, web, or infinitely tight mesh; neither of the two curves can ever cross itself, but must fold back on itself in a very complex way in order to cross the links of the web infinitely many times. One is struck with the complexity of this figure that I am not even attempting to draw (Poincaré, quoted in Stewart 1989 pg 71).

Figure 3.2: Phase space and Poincaré sections



To see the structure within, a computer can take a slice through an attractor, a so-called Poincaré section. The technique reduces a three-dimensional picture to two dimensions.

From Gleick (1987) pg 143.

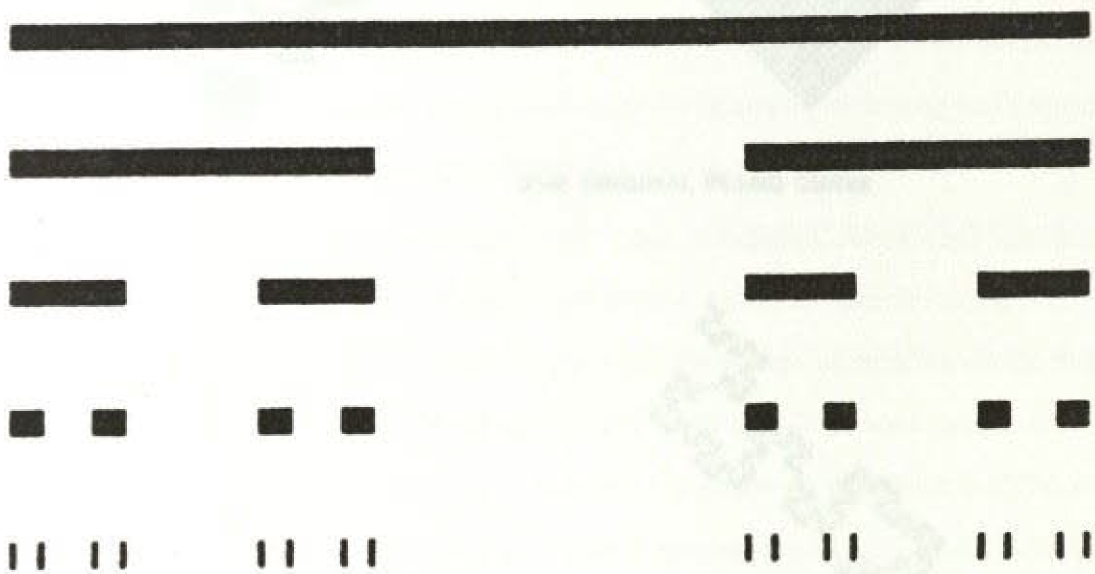
He realized that this set of points was a relative of the type invented just a few years before by Georg Cantor (fig 3.3). Cantor had developed this new construction as a way of testing the possibilities of set theory. He began with the real number line from 0 to 1, and removed the middle third. This left two smaller lines, and the same procedure was applied to these. By allowing this recursive operation to be carried out an infinite number of times, Cantor produced a simple example of what we now call a fractal. At the time, however, modeling the real world was far from Cantor's interest. In fact, his motives were just the opposite: he was attempting to show that mathematics can point beyond physical reality.

Chapter 5 will deal with Cantor's life in greater detail; in this context it is sufficient to note that his construction (dubbed the "Cantor dust" by Mandelbrot) was the first of many recursive forms (fig 3.4), and that none of these were proposed as applicable models of anything. Their value was in what seemed to be an extreme "pathology." Since any tangent to the curves changed angle depending on the scale they were viewed on, they could not be subjected to differentiation. They had infinite length within finite bounds, and seemed to defy ordinary topological notions.

Despite his advances in celestial mechanics, Poincaré found this infinite complexity too unnerving to pursue. The planetary orbits were an "unapproachable rampart," with only occasional areas of linear behavior in which he could "penetrate the fortress" (quoted in Ekeland 1988). This bodily imagery by which he rejected chaos in physics was also used by him in rejecting chaos in mathematics. "Cantorism [promises] the joy of a doctor called to follow a fine pathological case" (quoted in Mandelbrot 1982). Other mathematicians followed Poincaré's lead, disregarding the non-differentiable functions as unnatural aberrations, a "gallery of monsters."

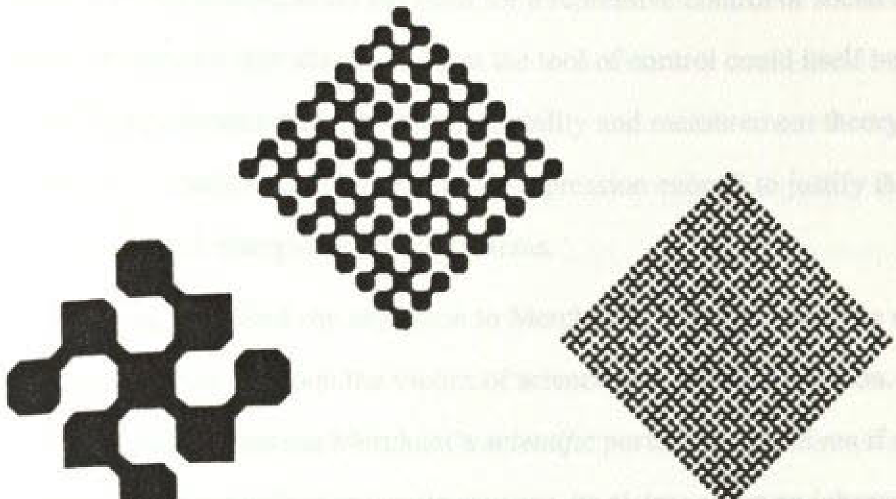
This rejection of chaos by science, particularly in the bodily terms quoted above, is quite consistent with Merchant's ethical holism stance. According to her history,

Figure 3.3: The Cantor set

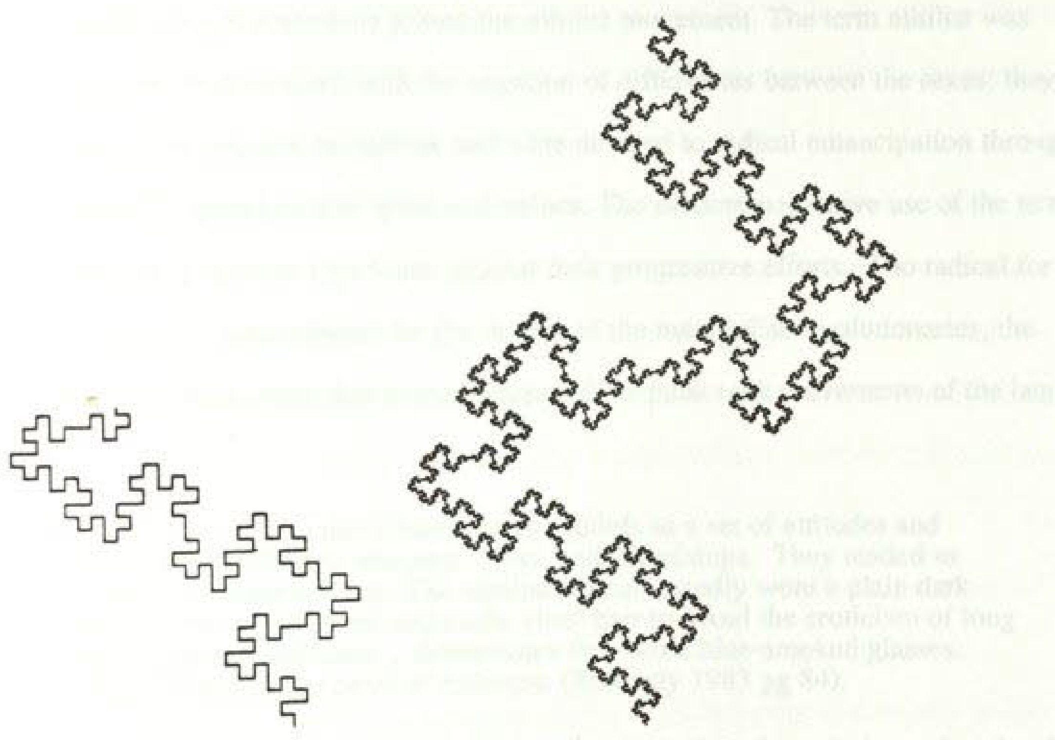


Generated by the author using FractaSketch by Dynamic
Software Inc.; dist. Aerial Press, Santa Cruz.

Figure 3.4: Some early (pre-Mandelbrot) fractals



THE ORIGINAL PEANO CURVE



MINKOWSKI SAUSAGE

Mandelbrot 1982.

mathematics had just instituted a regime of control over the disorder of Nature; one which resonated with discourse on the need for a repressive control of social chaos (eg the control of womens's reproduction). That the tool of control could itself become chaotic, disrupting calculus with nondifferentiability and measurement theory with fractional dimensions, would seem to threaten this repression enough to justify the horrified reactions and eventual disregard of these systems.

I have already indicated my objection to Merchant's social portrait: the eco-utopian premodern past was not so much the victim of science as it was its invention. But the previous description still leaves Merchant's *scientific* portrait intact. Even if ethical holism is wrong about its imagined romantic savages, its claims about an inherently repressive attribute in scientific order and artificial analysis has yet to be contested.

One such contestation can be found in the work of Sophia Kovaleskaia. Born in Byelorussia in 1850, Kovaleskaia joined the nihilist movement. The term nihilist was chosen to signify their concern with the negation of differences between the sexes; they were actually quite positive in outlook and were devoted to radical emancipation through education and the spread of new ideas and values. The modern pejorative use of the term came much later, in part as a backlash against their progressive efforts. Too radical for the liberals, and too open-minded for the dogma of the materialist revolutionaries, the nihilists formed a subculture that is reminiscent of the punk rock movements of the late 1970s.

> The nihilists did not so much have formal beliefs as a set of attitudes and values, even extending to manners, dress, and friendships. They tended to avoid organized movements. The nihilist women usually wore a plain dark wool dress with white collar and cuffs, short hair to avoid the eroticism of long hair and elaborate coiffures.... Sometimes they wore blue-smoked glasses. Many were direct to the point of rudeness (Kennedy 1983 pg 84).

That there are echos of the nihilist dress and style in the mirrorshades and mohawks of the late 20th century is not coincidence; both subcultures were intent on legitimizing

the artificial as an opening to new identities and social relations. The release from 'natural' determination of gender roles was signified by the 'unnatural' short hair and high-tech gaze of artificially mediated vision. Kovalevskaya's mastery of mathematics was also a part of this radical semiotics.

The use of fictitious marriages became a common strategy for nihilist women seeking family and state permission to leave home for work or study, and Kovalevskaya was one of the first to take this route. Following a brief participation in the Paris commune of 1871, she found surprising support for her mathematical work from one of the most eminent mathematicians of the era, Karl Weierstrass. In this respect Kovalevskaya was the opposite of Ada Lovelace: the Russian achieved her status in the scientific community despite (rather than because of) her social affiliations; it was the extraordinary power of her mathematics that carried her through. Her work in the theory of partial differential equations (in particular the Cauchy-Kovalevskaya theorem) is still in use today. She was particularly well known for her ability to apply Weierstrass' power series method to some of the most complicated problems known in analysis.

Kovalevskaya's social affinity for a non-natural realm was also reflected in her mathematics, and could well have been one of the reasons for the support she gained from Weierstrass. Not only was Weierstrass interested in non-differentiable functions such as those of Cantor, but his general philosophy was often referred to as "analysis for analysis' sake," with no concern for the question of application to modelling natural systems.*

It is certain that Kovalevskaya had some effect on Poincaré's work; her study on partial differential equations is mentioned in his "Oscar," and Kovalevskaya was an active participant in the dinner discussions of the Paris mathematics community in the

*The term "analysis" here has a technical meaning, referring to a branch of mathematics which provides the theoretical basis for calculus.

period preceding his award. While Poincaré's celestial mechanics took a completely new step - showing that there are some differential equations whose phase space contains non-differentiable sets, and thus defeating the possibility of an analytic solution - it was Kovalevskaya that had taken Weierstrass' power series method right up to this edge. Considering that it was her study which brought analysis to this point, and considering her knowledge (through Weierstrass as well as her acquaintance with Georg Cantor) of nondifferentiable sets, it is not unlikely that Kovalevskaya played a role in Poincaré's discovery of celestial chaos.

Despite the convergence of interest - and possibly collaboration - of the two mathematicians in this chaotic realm, the psychological and cultural signification of this discovery was quite different. For Poincaré the intrusion of chaos into the heavens (and into the archetype of order itself, mathematics) was an upsetting confusion of boundaries. For Kovalevskaya it was an opening of liberatory space, and boundary confusions themselves were useful resources (as exemplified by her reference to her own award-winning work as the capture of a "mathematical mermaid" (Kennedy pg 249)).

I've used Merchant as a foil in this description not because she's a flawed or easy target, but because I think she is historically accurate and compelling. My only complaint with her work is her implication that the social phenomenon she describes is an inherent, universal property of the vitalist/mechanist dualism, whereas I see it as one possible social convention. The exceptions this section has pointed to do not refute her historical portrait, they merely shift the explanation from natural determinism to social construction. While the forces of masculinist capitalism and other grand systems of social repression brought overwhelming reinforcement to Poincaré's interpretation -- and set this formula of order over chaos as a primary cultural theme for the modern era -- Kovalevskaya's perspective stands as a reminder of the arbitrary nature of such associations, and of the ability of even the most objective of the exact sciences to act as an

expressive medium for the most subjective of cultural processes.

3.3 Modern Chaos: safety in numbers

In the last section, the psychological and cultural construction of chaos in Nature was seen as a response to chaos in the social sphere. In both arenas, signifiers of chaos and order expressed tensions over boundary distinctions of economic class, gender, and other hierarchized social categories. This was also true for mathematics. Here at the stronghold of modernist order, the very definition of "boundary" had been perverted from within. In this section I will briefly describe some of the ways in which these upsetting confusions were dealt with in modernity, and in the next section their dramatic re-evaluation at the onset of postmodernism.

One of the consequences of this desire for safety in category separation was the exclusion of mathematical chaos from the chaos of nature. Neither the actual structure of the non-differentiable sets, nor the differential equations which produced them in the more abstract phase space portraits, were used by scientists interested in mathematical models. Nature was the proper place for the uncontrollable, and "her" taming required tools which were properly controlled.

One method of ensuring this strict rigor was linearity. Linear equations maintain an obedience to their initial conditions; they will not become chaotic. Linear systems have the property of *superposition:* the response due to several simultaneous inputs is equal to the sum of the responses for each input taken individually. There is no synergy in linear systems, no surprises - and thus total prediction. That much of the world is actually non-linear poses some problems for this approach, but "linearizing" an equation is often possible (for example, approximating a curve by a series of linear steps), and one could often restrict research to the linearizable portion and still find plenty to publish. The game theory world of von Neumann (examined in chapter 1) is a good illustration of the con-

vergence between linearity of control and prediction in mathematical terms and its parallels in the social domain.

There is another facet to chaos however, and that is complexity. Playing on the word "chaos," the Dutch chemist J.B. Van Helmont invented the word "gas" in 1632. Gases have served as the archetype for modernist complexity. Although the behavior of each molecule in the gas is totally deterministic, following Newton to the letter of the law, their aggregate behavior appears random due to the huge number of interactions. Even with complete linearity, if there is an astronomical number of components acting independently, then the exact behavior of the system will be impossible to analyze. By developing probabilistic models, mathematicians contributed tools which turned these large numbers into a predictable entity.

Metz (1987) sees the rise of statistical mathematics as a marker for the onset of modernity.

> Industrialization and urbanization produced large numbers both by assembling many people in limited areas and by augmenting the dependences and interrelations in a social environment. ...Statistics, consequently, was more that just a methodological device. It was... a perspective genuinely in harmony with the statistical structure of modern society.

Here I want to look at specific work in mathematical sciences of this period, and examine the social meanings that these innovators ascribe to their work.

There is a long-established fascination with gambling in the mathematics community; an interest rising from gambling's unique junctures between the abstract substance of mathematics and the concrete experience of its particular social interactions (not the least of which being that distillation of social power, money). The first book on probability theory, including work by Pascal, Fermat, and Huygens, was *On Reasoning in Games of Chance* (1657). As probability theory became a subject in its own right, it began to develop an applied side - statistics - which entered the modern armament against chaos in

the late 19th century. Thanks to the work of astronomers in attempting to overcome observational error by averaging, the bell-shaped "normal distribution" became known in mathematics. It was generalized as a statistical tool by Adolphe Quetelet in his *Social Physics* of 1869, where the "error law" was applied to measurements from physiology to crime frequencies (Lécuyer 1987). Here the mathematical norm became a moral norm, and the elimination of errors due to noise was converted to an ominous program for social perfection.

Quelet's work on the normal distribution was taken up by Francis Galton, who was primarily interested in heredity. Using data on sweet peas, Galton developed the idea of regression towards the mean, and from there regression analysis - extracting underlying trends from random data. He was particularly interested in using the quantification of character to guide human inheritance, although this presented problems in measurement. Following his trip to South Africa, he proposed that the relative worth of whites and Blacks could be objectively assessed by examining white encounters with Black chiefs, for although "a native chief has a good education in the art of ruling men.... it is seldom we hear of a white traveler meeting with a black chief whom he feels to be the better man" (quoted in Gould 1981, pg 76). Convinced that his statistical models of heredity had pointed the way towards extracting the order of progress from the chaos of genetic regression, Galton coined the term "eugenics" in 1883 in his advocacy of the regulation of marriage and family size according to hereditary endowment.

This is not to say that the social significance of statistics was uniformly one of chaotophobic elitists. For example, Quetelet's work was also taken up by Florence Nightingale (Cohen 1984). Although Nightingale is usually recalled as a stereotype of feminine self-sacrifice, she was an accomplished statistician, and studied pure mathematics under James Sylvester. Using Quetelet's notions of error from the norm to quantify her own ideas about "unnecessary death" in urban environments and warfare, Nightingale

not only pushed vast improvements in health reform, but also invented the polar-area diagram as a way to allow non-experts to visualize her quantification for the preventability of war and poverty-related deaths. Much of her work was in collaboration with William Farr, who often receives sole credit for these studies. Not surprisingly, the work of Farr and Nightingale was attacked by Francis Galton, who claimed it was unsound in both mathematical and social theory (Galton 1877).

Another important exception to the 'chaos v.s. order' social theme of statistics took place in Germany. Here Quetelet's ideas of establishing social laws from statistical averages was sternly opposed as a denial of free will. Porter (1987) notes that while these rejections were often couched in progressive notions of the heterogeneity of communities, they were also in reaction to the association of worker radicalism with such notions of "social laws" in the socialist-materialist theories. In addition, the influential German statistician Gustav Rümelin carefully qualified this free will as being more present in "animals... than plants, people than apes, moderns that ancients, adults than children, Caucasians than Negroes, men than women, and educated than uneducated" (Porter pg 364).

Hacking (1987) suggests that the German rejection of social determinism was specifically within a "conservative holism" tradition which used notions of organic harmony to push for institutions that would maintain elite control in the face of increasing working-class opposition. Wise (1987) describes some of the ways in which this German valorization of organic variation and indeterminism in society may have influenced the development of their quantum mechanics. Section 3.7 will show how this Germanic appreciation of disorder was used in their WWII military organization, and the U.S. adoption of this military philosophy in its attempts to adapt to postmodern chaos.

It is important to understand that the "chaos" in this modernist sense only existed as an overwhelming complexity due to huge numbers of interactions. It was unpredictable,

and therefore *virtually* indeterminant, or operationally random. That free will or quantum phenomena might be examples of truly indeterminant, non-causal events was an interesting addition, but did not change this definition of chaos as structurelessness or white noise. As Hacking (1986) notes, the "taming of chance" in 19th century Western Europe was as much social as it was mathematical; the two conceptions merged in their attempt to extract linear, deterministic order from a chaos that was defined as randomness due to complexity. As always, I want to emphasize that these meanings are culturally derived. Nightingale serves as an ethically positive counter-example -- opposition to the deadly carelessness of military-industrial capitalism through her exacting statistical work. German rejection of statistical determinism serves as an ethically negative counter-example -- a suppression of radical worker's resistance by rejecting the philosophic basis for their social theory.*

Following Galton, the major theoretical activity in statistics returned to the physical sciences, where it revolutionized thermodynamics, chemistry, and many other disciplines. In the social sciences mathematical notions of disorder continued to parallel cultural tensions over race, class and sex (see Gould 1981 for a classic account of this history in psychophysiology) The physical science version of disorder was briefly put directly into a social science framework in the form of the Technocracy movement of the 1930s (Akin 1977). In its founding text *Science versus Chaos!* (Scott 1933), this modernist order-topia proposed to replace the destabilizing complexity of "the price system" with equal allocations of nonaccumulable energy certificates. By reducing all materials and work to unified thermodynamic units, engineers would make neutral value-free organizational decisions.

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*Or at least the social theory that was associated with them. The anarchist-inspired Dresden uprising of 1846 suggests that there were other intellectual currents at work besides that of socialist-materialism.

Although much of the statistics from both social and physical sciences was on the outskirts of pure mathematics, even at the center of this acme of abstraction the basic definitions of chaos remained the same: a complexity that defied specific analysis, and whose global analysis required probabilistic methods. The essence of this modernist definition of complexity was developed in the work of Soviet mathematician A. N. Kolmogorov.* Noting that apparently random numbers can be completely determined by a simple algorithm, Kolmogorov proposed that the "algorithmic complexity" of a number was equal to the length of the shortest algorithm required to produce it. This means that periodic numbers (such as .121212121...) will always have a low algorithmic complexity. Even if the number is infinitely long, the algorithm can simply say "repeat 12 forever." Truely random numbers (eg a string of numbers produced by rolling dice) will have the highest algorithmic complexity possible, since their only algorithm is the number itself -- for an infinite length, you get infinite complexity.

In the postmodern era this definition is completely transformed. Neither chaos nor complexity is captured by the notion of randomness or gas-like independence of interactions. It is defined, instead, by the long discarded monsters of Cantor. While the social conditions of modernity kept these beasts safely at bay, maintaining a strict boundary between the order of mathematics and the chaos of nature, the postmodern condition is one in which these lines are purposefully and productively blurred.

3.4 Chaos in the Postmodern Era: the simplicity of complexity

As mentioned earlier, Poincaré made a hasty retreat from his brief encounter with the Cantor set, and led the way towards confining these non-differentiable monsters to quarantine in the pathology wing or harmless display in a side-show. His reaction was echoed by several of his contemporaries. Charles Hermite, for example remarked "I turn

*Similar proposals were put forward by Gregory Chaitin and Ray Solomonoff in the 1960s.

with fear and horror from this lamentable plague of functions that have no derivatives" (quoted in Heims 1980 pg 70). This revulsion severely limited the institutional and conceptual resources applied to these demons of analysis. As Saks (1937) notes, "Researches dealing with non-analytic functions and with functions violating laws which one hoped were universal, were regarded almost as the propagation of anarchy and chaos where past generations had sought order and harmony" (preface).

The rebirth of these chaotic equations as heros of postmodern mathematics has been as much a surprise to mathematicians as it has been to researchers in historical and philosophical studies of science. With the exception of Norbert Wiener's model of brownian motion, the non-differentiable functions were never used in any application. In pure mathematics the monsters were allowed on stage at the end of analysis texts as a sort of comic relief, not to be taken too seriously, and at best as evidence of the abstraction and other-worldliness that mathematics could produce (eg Vilenkin 1965). By 1926, Cantor's monsters could be safely valorized by Hilbert, the leading mathematician of formalism (the "complete and decidable" school of von Neumann, finally defeated by Kurt Godel in 1931): "No one shall expel us from the paradise which Cantor created for us." Having been thoroughly rejected as too monstrous for consideration as physical entities, they became proof of a non-physical realm that was safely insulated from any boundary transgression.

Benoit Mandelbrot's 1977 *The Fractal Geometry of Nature* was the seminal move in releasing the non-differentiable functions, and Mandelbrot took great pleasure in emphasizing their previously demonized status. With parental assurance, the father of fractal geometry chides mathematicians for their nightmare. The headings for figures in his text include "Harnessing the Peano Monster Curve," "Fractal Tree Skeleton," "The Devil's Terraces," "Self-squared Dragon," and similar phrases. Like any good parent, Mandelbrot lets us laugh at our fears. He bids good scientists everywhere to rise from

the linear dream and waken in the postmodern sunlight: "You see? That dragon you saw was just a wrinkled sheet."

Other branches of chaos theory also came as a sudden transformation, all during this short timespan of the early to mid-70s. While Poincaré's nonlinear dynamics had uncovered chaos in the simple (that is, low dimensional) differential equations of planetary motion, simplicity was not compatible with modernist notions of complexity, unpredictability or aperiodic behavior, and his observations were disregarded (due as much to his own rejection as that of anyone else). The same story is repeated in the early 1960s in the case of Edward Lorenz, a meteorologist at MIT. Although there was no self-rejection here, Lorenz's discovery of chaos was also clearly stated -- the title of his key paper was "Deterministic Nonperiodic Flow" -- and also ignored.

Lorenz is striking in his modesty. He is easy to spot at any scientific conference; just search the sea of suits for the one man with a cardigan sweater and no axe grinding. Whether this stems from his small-town New England upbringing or from some other part of his identity, I do not know. It is interesting to note that Norbert Wiener used his New England town meetings as an illustration of decentralized feedback loops, and was the only mathematician to use deterministic chaos as a model of physical systems (in his work on Brownian motion) until Lorenz. Wiener also foresaw this possibility in weather systems, noting "self-amplitude of small details of the weather map" (quoted in Gleick pg 322).

John von Neumann was also interested in differential equations as predictive models for the weather, but his assumption was quite the opposite of Lorenz's chaos. He gave inspiring talks to the physics community about the long-term prediction that computers would provide for weather forecasting, and his ultimate goal of controlling the weather. It is not surprising that someone with von Neumann's elitist convictions and obsession with order would fail to appreciate computational mathematics itself as a

source of chaos.*

Lorenz, to the contrary, seems amused by the defeat of complete weather prediction, never failing to recall the moment without a wide grin. "We certainly hadn't been successful in doing that anyway, and now we had an excuse" (Gleick pg 18). His own history of his work (Lorenz 1978) does not cite von Neumann at all, but instead starts with L.F. Richardson, a Quaker pacifist who destroyed all of his unpublished research on turbulence when he discovered that it was being used in chemical warfare studies (Gleiser 1980). Lorenz reports that he began to search for differential equations that produced aperiodic behavior, with the specific intent of showing the inappropriateness of the statistical approach to such deterministic variation. One day Lorenz happened to put in a truncated version of his initial conditions -- .506 instead of .506127 -- and was surprised to see the output of his equations quickly show a wild divergence from an almost identical starting point. Lorenz says that he initially assumed a machine error, since the computer they used was quite unreliable. But when he realized that the initial conditions were slightly different, something clicked.

Lorenz realized that the tiny difference between the two starting conditions had become amplified, and eventually dubbed this "the butterfly effect." Due to this sensitivity to initial conditions, a tiny perturbation could be amplified into a change in huge weather systems. Most significantly, he realized that this was connected to the never-ending variation of the output. Eventually he was able to map these changes into phase space, producing not only Poincaré's slices of "infinitely tight mesh," but the entire global attractor of the system.

*Von Neumann defenders might argue that he would have discovered this himself had he simply used the right equations, but Michael Nauenberg (in lecture, 1991) reports that one of the first calculations von Neumann tried on a computer was the logistic equation with the driving parameter at 4 -- a classic chaos system.

Why wasn't Lorenz's discovery in 1963 the starting point for the postmodern chaos revolution? Why was appreciation of his work delayed by more than a decade? Glieck suggests a parallel between the conceptual reductionism that prevented chaos from being conceived, and the reductionist institutional structure of science as separated disciplines, but also sees this as delay as reasonable: "Physicists had better ways to spend their time than sifting through the metrology journals." Stewart (1989) also ridicules the notion that this could have circulated: "Yes, it's just barely possible that the Spring issue of the *Goatstrangler's Gazette* might contain an idea of enormous importance in dynamical systems theory, but the same goes for a thousand other obscure journals too" (pg 134). But Gleick cites several non-meteorological researchers who *did* know about Lorenz. Edward Spiegel, for example, was a cosmologist who knew Lorenz personally, and had tried unsuccessfully to interest others in his idea. In another section of Gleick's text he notes that a fluid dynamicist had come across Lorenz's paper and "had fallen in love with it, handing out copies to anyone who would take one" (pg 6). Apparently, few would. Isolation is not the sole factor in the delay of chaos.

Lorenz's paper eventually made its way to James Yorke, a mathematician who admired Smale for his politics as well as his mathematics. Gleick reports that Yorke had made direct use of his mathematical skill during the antiwar demonstrations in his analysis of a fraudulent government photo. Like Joesph Ford, quoted in the last chapter on the staunch resistance to deterministic chaos he encountered in his thermodynamics group, Yorke found that ignorance was not the sole explanation: "physicists had *learned* not to see chaos" (Gleick paraphrasing, pg 67). While Yorke found a small group of researchers who quickly took up the cause, he was also found many that did not see anything useful or attractive in the notion of deterministic aperiodicity.

What makes the story particularly interesting at this point is that those whom Yorke was able to interest in the Lorenz papers were already formulating their own work in

these directions. Robert May was Yorke's first convert, but May had already found deterministic chaos in his use of the logistic map for biological population models (May 1976). Yorke found that his 1975 seminal paper, "Period Three Implies Chaos," was well received in the Soviet Union, but they had already adopted Smale's work to problems in thermodynamics at that time (Gleick pg 76). Meanwhile, David Ruelle and Floris Takens in Paris had already (1971) coined the term "strange attractor," the German medical doctor Otto Roßsler (1976) demonstrated the possibility of deterministic chaos in equations for biochemical systems (an idea he reports to have conceived while watching an automatic taffy puller), and Yoshisuke Ueda* (1973) had found aperiodic behavior in electrical circuits in Japan. Unless we are willing to cite capacitors and taffy machines as social actors, genealogies are not the whole explanation either.

While I am trying to push for the notion of a cultural zeitgeist, I do not want to suggest that the internalist accounts are irrelevent -- just the opposite. To use a deflection metaphor, suggesting that science is bent by 'external' forces, or to say that 'internal' genealogies and conceptual exchanges are of limited importance, actually *supports* the internalist account by confirming a static internal/external opposition. It is important to see that punk rock and aperiodic equations are both part of the same social dynamic, and that in their opposition they give rise to each other, but it is equally important to see how this social dynamic is expressed within/through science itself. In particular, the details of transdisciplinary scientific paradigms -- common ways of seeing experiments and theories that stretch from biology to bifurcation mathematics, the international flow of metaphors, problems and concepts within and between scientific communities -- offer a way to take this notion of zeitgeist beyond its ineluctable ambiguity and use it as a

*Ueda actually suggested this phenomenon in the early 1960s, but his advisors told him, "Your result is no more than an almost periodic oscillation. Don't form a selfish concept of steady states" (Gleick pg 141).

specific analysis of technosocial change.

3.5 Interpretations of the Chaos Revolution: the internalist views

In this section I want to examine the notion of a "chaos revolution" -- a sudden transition, across many disciplines, to new experiments, theories, and mathematical systems that were based on deterministic aperiodic behavior. By "interpretations" I mean not only causal explanations for the sudden change, but also the meaning of this change. In particular, we will see that while the internalist explanations for the transition tend to be rather stark -- and therefore unappealing to the historian searching for richer accounts of the scientific process -- a "thick description" of the chaos revolution can be produced by moving further *towards* the internalist view, by attempting to bring these internal explanations of the scientific community under observation, rather than abandoning them to the scientists' own promise that they hold only logical relations of value-free optimal simplicity.

The internalist accounts of chaos theory are generally of two schools. In the minority are those who suggest that there is no revolution at all, but simply a tremendous amount of publicity and hype over something that has been happening all along. This is often the response of Soviet researchers*, and is perhaps best typified in the US by the review by Steven Krantz (1989) concerning texts edited by Peitgen on fractal geometry. Krantz produced some illuminating self-contradictions in this attempt. Although his view essentially condemns fractal geometry as lacking in orthodox mathematical content, his article was rejected (after a long and disagreeable debate) from a journal which embodies proper mathematical legitimacy, the *Bulletin of the American Mathematical Society,* and was finally accepted by the *Mathematical Intelligencer,* which is equally

*And not without good reason. The Soviet tradition in areas related to nonlinear dynamics is well known, and the pre-70s work of Kolmogorov, Markov, Lyapunov, and Arnold still stand out in chaos theory.

prestigious but known for its appreciation of social and technical heterodoxy within the mathematics community. In addition, his critique disregarded the importance of recursive models demonstrated by fractal geometry, but used this very concept to make the point.

> The hypotheses and conjectures that the fractal people generate are (like the objects which they study) self-referential. One generates the pictures to learn more about the pictures, not to attain deeper understanding. (pg 15)

This rejection of a chaos revolution is in strong contrast to the rejections of catastrophe theory by the mathematical community (see Smale's review, reprinted in *Dynamics of Time),* in which critiques mourned the impotence of its empirical support. The unintentional trope of chaos rejections by Krantz and others is not tragedy but irony. His cry for orthodoxy can only be printed in an unorthodox journal; his strongest critique of self-reference is self-referential. Rather than pointing out failures of chaos, Krantz and others are actually protesting against its non-normative success, which they correctly see as a blurring of the boundaries that once defined proper mathematical progress. It is not that the emperor has no clothes, but that he used tailors from outside the royal court.

The more common internalist view is that the sudden emergence of chaos is due to one factor: the availability of digital computers. John Franks (1989) put this baldly in his negative review of Gleick's famous popular text *Chaos -- making a new science,* where he insisted that Gleick had missed "the obvious explanation of the sudden interest in chaos in many branches of science," which was "the advent of inexpensive, easy-to-use digital computers" (pg 65).

> There is indeed a revolution in progress, but it is not, as the book suggests, the "Chaos Revolution." Instead it is the computer revolution, and the current popularity of chaos is only a corollary. ...It surprises us because it was invisible before the computer, but with computers it is easy to see, even hard to avoid (pg 66).

In a rebuttal to Franks' review, Gleick did not disagree with the explanation, but quoted

his own perpetual and insistant observations on the importance of computers, which Franks oddly seemed to have overlooked (and one which he apologized for in his reply). This explanation of technological determinism is quite common in both popular and professional circles. For example, it was included in Heinz-Otto Peitgen's introduction to his fractal geometry course at UCSC, in Stewart (pg 138), in Pagels 1988 (pg 85), and even by Benoit Mandelbrot (1989 pg 6).

I have no disagreement with this periodization, or the notion that the emergence of chaos and computers are linked. But the direct causality, the idea that deterministic chaos is simply the inevitable outcome of having lots of computers around, seems quite mistaken. For one, the idea of deterministic aperiodicity clearly arose in the 19th century; its disregard was due to interpretation, not instrumentation. Second, both mathematical and empirical descriptions of such phenomena continued to occur throughout the first half of the 20th century. Several of these instances are documented in Ralph Abraham's (1984) excellent pictorial introduction to dynamical systems theory. For example, in 1927 Balthasar van der Pol found aperiodic frequency fluctuations in self-excited electrical circuits, but his observations were not seen as particularly significant. They were finally taken up by Mary Lucy Cartwright, who collaborated with James Littlewood in 1945 on a mathematical analysis of the equations governing van der Pol's oscillator. George Birkhoff discovered the chaotic attractor ("remarkable curve" as he put it) as a theoretical object in 1912, and it was further developed by Marie Charpentier in the 1930s. Chaos didn't die with Poincaré, it was just relentlessly ignored. The fact that two of these overlooked researchers were women may reflect some of the cultural associations for this area of study (as I've already indicated in section 3.2 of this chapter).

Another reason for doubting the technological determinism rational is that the emergence of chaos as a legitimate and valuable research topic in the early 1970s was not always accompanied by digital computers. For example, Gleick notes that Mitchell

Feigenbaum's crucial contribution of universal sequencing in transitions to chaos was not initiated through the computing facilities at his Los Alamos lab, since the few available computers there were given priority to the Weapons Divison. Instead, calculations were ground out on a tedious hand calculator -- quite fortunate, since the computer might have prevented his new insight.

> In the end, it was the slowness of the calculator that led him to a discovery that August. ...With a fast computer, and with a printout, Feigenbaum might have observed no pattern. But he had to write the numbers down by hand, and then he had to think about them while he was waiting, and then, to save time, he had to guess where the next answer would be (pg 171).

Mandelbrot's initial discovery that the scaling properties of nondifferentiable functions could model common examples of physical irregularity was based on hand-calculated data (eg Hurst 1951), and it is not particularly difficult to produce graphic illustrations of fractals of several recursive iterations by hand. The extreme for this case is exemplified by the hand drawn "circle limit" illustrations of M.C. Escher, which were based on the hyperbolic tilings of mathematicians Fricke and Klein (1897). Morris Hirsch (1989) points out that much of the mathematical foundations of chaos theory, particularly that of Smale, were carried out by mathematical proof with paper and pencil (although this leads him more towards the first interpretation; in his conclusion he refers to "the nonexistent science of chaos.")

Most importantly, several of the chaos discoveries of the 1970s were made on *analog* computers. This was true for Ueda in Japan, Rößler in Germany, and Rob Shaw in the US. Shaw's case is particularly significant, since he initiated the local "Chaos Cabal" at UCSC, an unofficial group of physical science students which both set some of the counter-culture flavor of chaos in the popular media, as well as influencing a number of technical communities in the early 1980s. Bass (1985) has described the non-professional side of the Cabal's activities: mixing the traditional mathematical interest in gambling* with the group's expertise in physical dynamics, they made a somewhat

successful attempt to develop a miniaturized computing system that could, in the confines of a casino, predict roulette wheel spins.

In late 1976 Shaw was simply playing with an old analog computer at UCSC as a side interest in the visualization of differential equations; he was officially only a month or two away from completing his PhD in low-temperature physics. But at the request of William Burke, a cosmologist who had become interested in the Lorenz equations as a result of his conversations with Spiegel, Shaw tried the Lorenz system out on his analog machine. The resulting phase space visualization was like nothing Shaw had ever seen, and in January of 1977 (Shaw, personal communication), the notion of deterministic chaos came as a stunning revelation. Gleick gives a very qualified recommendation for the advantages of analog representation:

> In the evolution of computers, analog machines represented a blind alley. ...Digital computers... gave precise answers... and they proved far more amenable to the miniaturization and acceleration of technology that ruled the computer revolution. Analog computers were, by design, fuzzy. ...The calculations were not quite precise. Numerical computation is side-stepped. Instead you have a model made of metal and electrons, quite fast and -- best of all -- easily adjustable.

While Gleick repeats the modernist story of analog systems as the digital computer's extinct ancestor (in this case a living fossil), his account does not mention the mythology of an inherent lack of universality so common in the 1960s (cf Singh 1966 pg 96). A new appreciation for analog systems was just barely being articulated at the time

*One odd commonality in the chaos community is a fascination with motorcycles (at UCSC mathematicians Heinz Otto-Peitgen, Gottfried Mayer-Kress, and Debbie Lewis are cycle enthusiasts, as are several of their graduate students), which could also be seen as not only playing with chance, but also playing with ethnic and class identities (all of the above are white). The roulette computer project was initiated by Doyne Farmer and Norman Packard, who grew up in the American Southwest and at one point divided their time between gambling casinos and a scheme to smuggle motorcycles (particularly the famed Vincent Black Shadow) from Mexico. A "white trash" ethnic identity has only begun to merit serious consideration in cultural studies (work by John Hartigan of the UCSC History of Consciousness dept is the best in this area), but the correlations between trash and chaos are probably an important ethnic expression for this group.

of Shaw's work (preprint 1978, most extensive publication in 1984), but his approach took precisely this path. Not only was Shaw's method of analyzing equations and experimental data performed on the analog computer, but his theoretical analysis generalized this to the entire physical world. Using the classic communication theory of Shannon and Weaver, Shaw demonstrated that the hallmark of chaos, the magnification of initial uncertainties into large scale uncertainties, could be quantified in bits. While the mathematics was not entirely new -- a similar measure had been suggested earlier by Kolmogorov -- Shaw emphasized this change in terms of the creation of new information. In other words, his interpretation allowed any physical dynamic to be viewed as an analog computer.

The Chaos Cabal's professional break happened at a 1978 conference on condensed matter physics, organized by Bernard Huberman of Stanford University. When a scheduled speaker cancelled at the last minute, Huberman invited Shaw to speak, and the cabal was able to show off their repertoire of computer graphics and videos to an audience hungry for insight into the rumored paradigm. Soon after, Huberman collaborated with James Crutchfield, the youngest member of the cabal, and picked up the group's emphasis on physical systems as analog information processors. In separate efforts, both Crutchfield and Huberman would eventually (1986) propose new definitions of complexity, ones in which the most complex structures are not the most random, but are those structures which require the greatest amount of computation to describe. In such measures it is not the random homogenous gas which is complicated, nor the orderly periodic crystal, but the "in between" shapes of fractals, the self-similar structures produced by self-organizing processes.

At the same time that Huberman and Crutchfield were reinventing complexity, other researchers in both related and distant disciplines were coming to the same conclusions. I will go over this new definition of complexity in section 3.8, when I discuss the era of

stable postmodernity following 1987 -- a time in which the synthesis of both analog and digital made quantitative measures of this physically based computation possible. For now, I want to emphasize the interpretive aspect of this change starting in the transitional postmodernity of 1977. Shaw's mathematics differed little from that of Kolmogorov (which he did not know about during his initial investigations). What made it different was his interpretation of the loss in bits of information resulting from the sensitivity to initial conditions. He was well aware that this traditionally would have been called noise, but chose instead to call it a "source of information." In the conclusion of his text Shaw played with the possible role of chaotic dynamics in creative thought, and pointed to the information processing view of physical dynamics as an approach to the evolution of life.

This almost mystical view was something that had worked against analog cybernetic research in the 1960s, but in 1977 it became part of a legitimized analog obsession (one which I followed closely; at first as a believer). Contrary to the assertions of many theories of representation from the modern era, which saw analog systems as mere mimicry, incapable of self-referential independence, the new physical dynamics of chaos were brimming with recursive surprise. This is nicely illustrated by the sudden rise of cellular automata. Recall von Neumann's self-reproducing machines from chapter 1. Although he saw these as carriers of his New Order (quite possibly with the thought of carrying order through the nuclear destruction of that annoying source of disorder, organic life), these self-reproducing automata turned out to be a powerful source of mathematical chaos.

Von Neumann's initial plan was to have physical robots, but at the suggestion of Ulam he settled for a graphic abstraction, having a cellular grid in which each cell had only a small number of possible states, and with all changes in state governed by one set of rules (eg if more than 50% of an occupied cell's nearest neighbors are also occupied

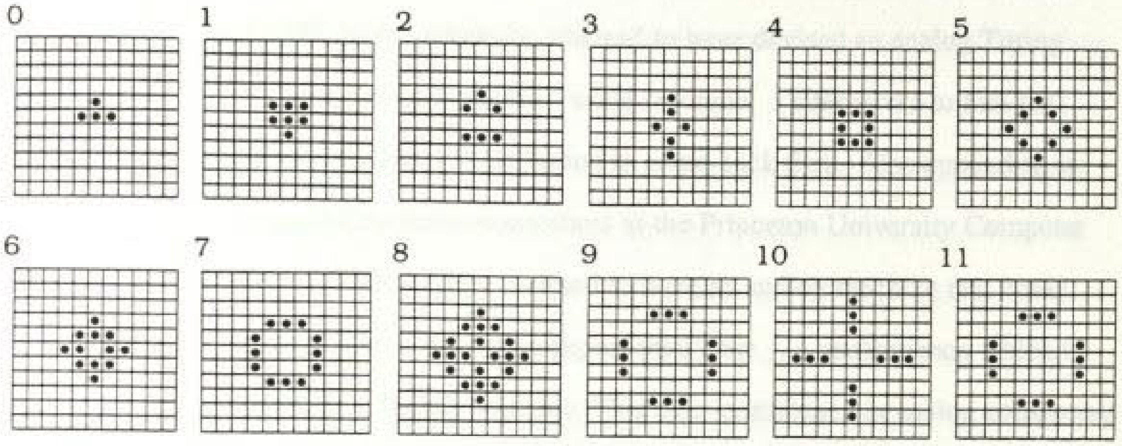
then it changes state). This was at first carried out on checkered table cloths with poker chips and dozens of human helpers (Mayer-Kress, personal communication), but by 1970 it had been developed into a simple computer program (Conway's "game of life") which was described by Martin Gardner in his famous "Mathematical Games" column in *Scientific American*. This column, which was later changed via anagram to "Metamagical Themas" by Douglas Hofstadter, and finally to "Computer Recreations" by A.K. Dewdney, has been a potent and turbulent site of mixture between professional and popular technical communities.

The "game of life" column was an instant hit, and computer screens all over the world began to pulsate with a bizarre array of patterns (fig 3.5). At the same time, and in part due to this popularization, researchers in various disciplines, from evolutionary biology to the mathematics of shift maps, began to give a fuller exploration to these systems. The key actor in bringing cellular automata to full professional status was Stephen Wolfram, who surveyed the general characteristics of cellular automata in a statistical mechanics framework (Wolfram 1983), as well as producing a theoretical proof for universal computation (ie equivalence to a Turing machine) in cellular automata (Wolfram 1984). Chaos Cabal member Norman Packard was also an early participant in this model of physical aggregates as computational structures.

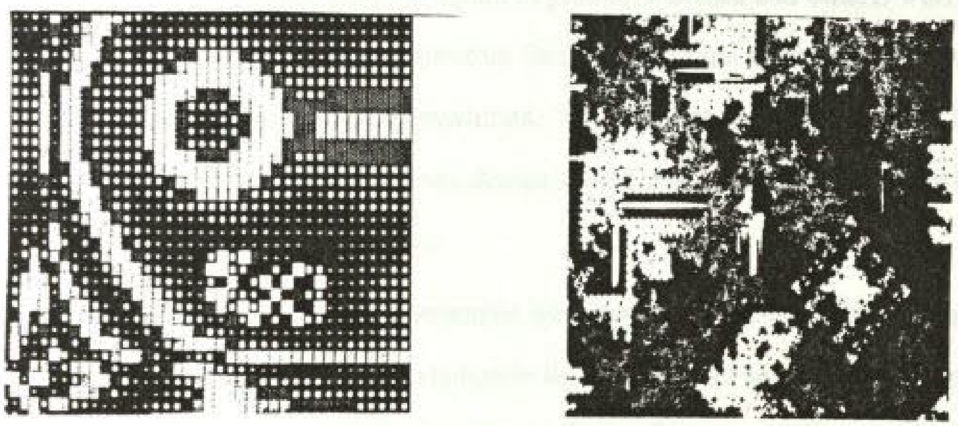
In 1984 Wolfram's reinterpretation was brought back to the "Mathematical Games" readers, although the column was now Dewdney's "Computer Recreations" -- a title whose double meaning was growing closer to reality.

> Immersed as we now are in a world of artificial computers it is interesting to consider the possibility that we are also surrounded by natural ones. Computers made of water, wind and wood (to mention just a few possibilities) may be bubbling, sighing or quietly growing without our suspecting that such activities are tantamount to a turmoil of computation whose best description is itself. This is not to say that such natural systems compute conventionally, only that their structure makes computation a possibility that is latent.

Figure 3.5: Cellular Automata



Simple example of "game of life" sequence (Peterson 1988 fig 7.1).



More complex patters generated with Rudy Rucker's *CALAB*

At the same time that Wolfram first announced his evidence for computation in physical dynamics, Dewdney was starting a series of columns on analog computing. This climaxed in his June 1985 essay, where he claimed to have devised an analog Turing machine which could out-perform a digital Turing machine. I later wrote to him for details, but he replied that his notes were buried in some back files. Also appearing at this time was an announcement from researchers at the Princeton University Computer Science Dept (Vergis et al 1985). They claimed to have an analog machine that could solve an NP-complete problem in less than exponential time -- a performance which is theoretically impossible for a Turing machine. This over-confidence in analog computing was not eccentric however; many scientists, inspired by the new computation of physical dynamics, began to feel that analog representation was in some sense superior. Mathematicians such as John Hubbard, who was known for his insistence on rigor, declared that the Mandelbrot set (a physical system in the sense that we can produce pictures of it) was "the most complicated object in mathematics." I am surprised at the number of prominent physicists (Pagels, Feynman, Penrose and others) who took refuge in quantum indeterminancy to claim that there are physical systems that have computational powers superior to Turing machines. The study of non-deterministic Turing machines is decades old, and has not demonstrated any indication that there is a computational advantage to these systems.

Researchers in the physical sciences were not the only ones entranced by analog systems. When I began this dissertation in the mid 1980s I sent a paper on my technical comparison of analog and digital systems to Walter Freeman, an expert in applications of nonlinear dynamics in neural systems at UCB. Freeman's reply was brief: "Your paper looks interesting. Can you show that there are analog systems, possibly implemented by the human brain, that process information not computable by a Turing machine?" Even in molecular biology, one place where the establishment modernists of the 1960s could

claim a triumphant victory in the appropriateness of digital models (ie the genetic code), analog dynamics suddenly became an crucial feature. This was launched by Karplus' "Dynamics of Folded Proteins" in June of 1977, and soon developed into a subdiscipline of its own.

Recalling certain anti-establishment modernists of the 60s, in particular the small cybernetics conference (M.C. Bateson 1972) attended by Bateson, Commoner, McColluch and others, I am struck by the fulfillment of their then-radical technical agenda. Commoner persistently cited his biological research attempts to show that the analog coding of information in the cell was as complex and important as the digital codes, and this defense of analog against digital became a general metaphor for issues of social control throughout the conference (eg pg 53). In my own research in zoosemiotics, I was quite influenced by Bateson and his cohorts, and was confused when I found that one of my least favorite zoosemiotics writers, biological determinist E.O. Wilson, was convinced that "all other circumstances being equal, graded messages convey more information than discrete messages" (pg 90; here he also states that by "graded" and "discrete" he means "analog" and "digital"). I was able to show the error in his model which gave him mathematical support for analog superiority (Eglash 1984 pg 171), but I was unable to understand how he could support it ideologically. I thought *our* side was supposed to root for analog.

This brief period of time, from 1977 to 1987, was only a transitional moment for postmodernism. I am particularly fond of it because it was a moment of instability, a time when the paint and glue weren't quite dry on the latest constructions of the military-industrial complex. Certainly E.O. Wilson could count on anthropologists like Owen Lovejoy to emphasize the need for analogical, right-brain thought in proto-human males, and Lovejoy in turn could be confident that the boys in cognitive psychology would find new evidence for the right-brain location of mathematical and other "male"

skills. But wasn't this reversal just a bit too fast?

Part of the difficulty in this change was trying to maintain the appearance of simple advancement. Kuhn's notion of paradigms was by now fully incorporated into common notions of science -- it had never been all that radical anyhow; nothing in the notion of "paradigm" suggests a rupture between internal science and its supposed external context. But just as youth subculture was able to find a revolutionary standpoint in its new love of artificial, digital, urban environs, the institutions and grand epistimological edifices of the First World and its old boy's club were able to maintain their dominance by embracing their previous opponent, the analog dynamics of chaos.

This dominance maintenance required both a new paradigm as well as the continuation of an old one. In the internalist view we see a legitimation of revolutionary change, but also its qualification as simply one factor in the bigger story of slow progress (sort of like covering the American Revolution in a US public school). The chaos revolution "is only a corollary" of the "computer revolution." But these scientists who claim that their interpretation of science history is only one of simple, direct technological causality are playing dumb. They know that when it comes to the *content* of science, their interpretations will be flexible, and sometimes downright paradoxical. It was by reinterpreting the physical world as analog representation, not by sticking to the old guns of progress in digital computers, that the chaos revolution made its real impact.

When I look at the politics of these first chaos theorists, it reminds me of the general post-sixties atmosphere. Gleick quotes Bernard Huberman's distaste at his first visit to the Chaos Cabal's lab/commune at 707 Riverside Street: "It was all very vague, you know, sofas and bean bags, like stepping into a time machine, flower children and the 1960s again" (pg 270). Had this actually happened in the 1960s their new dynamics might well have been at the forefront of Bateson's radical science contingent, but the Cabal was quite aware that their work was no longer in that context. There is an element

of sadness, for example, in Bass' description of their chaos party in 1977, where part of the house was converted into "a shrine commemorating the excesses of the 1960s." As Cabal member Doyne Farmer later said, "I had the sense of an era coming to an end." While a radical perspective may have led many of the early chaos scientists to the new direction, it was also clear that it was happening at a time when this direction had lost its radicalness. In his close on the Santa Cruz chapter, Gleick notes that

> Only Shaw seemed reluctant to join the mainstream. Several times, he came close to quitting science altogether. As one of his friends said, he was oscillating (pg 272).

Shaw's interpretation of the historical significance of his work is quite modest, at times even jaded. His caution is something that the political and cultural theorists writing about chaos are often lacking.

3.6 Interpretations of the Chaos Revolution: the externalist views

Both postmodernist and modernist externalist perspectives on the rebirth of chaos theory have tended towards optimistic and even utopian evaluations. The new scientific valorization of self-organizing systems and analog representation is taken by modernist cultural critics as vindication for their oppositional politics in the 1960s. Griffin (1988) for example belongs to a group of modernist radical science writers who, in a confusing neologism, refer to themselves as "constructive postmodernists." Adhering to the holistic traditions of Bateson and Weiner, they see chaos theory as objective proof for the superior perspective of humanist recursion and romanticist anti-symbolics. They distinguish themselves from my philosophic view, which they call "deconstructive postmodernism."

> [It] can be called *deconstructive* or *eliminative postmodernism*. It overcomes the modern worldview through an anti-worldview: it deconstructs or eliminates the ingredients necessary for a worldview, such as God, self, purpose, meaning, a real world, and truth as correspondence. While motivated in some cases by the ethical concern to forestall totalitarian systems, this type of postmodern

thought issues in relativism, even nihilism (pg x).

Throughout this text I'll continue to use "postmodernism" only to mean the deconstructive kind, although I will distinguish between the holism of the 1960s and a new "metaholism" that I associate with Griffin's paradigm. The disadvantage of Griffin's analysis is that he would characterize deeply spiritual people, such as myself, as nihilistic simply because we refuse to promote our own belief system as a universal epistemology. The advantage of Griffin's analysis is that he accurately recognizes a split that is difficult to reconcile. Like other splits in radical politics (idealists v.s. materialists, anti-sexists v.s. anti-racists, etc) each side can produce very different ideologies and activities, despite their common interests. Although the need for cooperative ventures is paramount, we can't fool ourselves into thinking that some simple compromise or transcendent perspective is easily available. When I see organicists willing to risk arrest in protests for the urban working class movements they intellectually disregard, or postmodernists putting labor and time into the ecology projects they intellectually critique, I'm filled with admiration and hope.

A second modernist analysis of chaos can be seen in David Porush's analysis of Gleick's text, delivered at the Society for Social Studies of Science conference in 1989. The paper centered around the absence of Prigogine's "order out of chaos" work in Gleick's account. Porush asked Gleick, who said that it simply didn't fit the particular story he was telling, and he asked Prigogine, who said that it was due to Gleick's bias against Europeans. Porush suggested that it was a political move. Prigogine's work is a scientific rebellion against the conservative modernist views of statistics noted in section 3.3. Through his studies on stochastic nonequilibrium systems, he has demonstrated that order (defined in terms of Euclidian geometry) can spontaneously and unpredictably arise from highly disordered (random, as in a gas) systems. His results would have been anathema to the statistical authoritarians of the Technocracy movement, and they have

Considering the diverse interpretations by both modernists and postmodernists, it would seem that chaos theory has become a sort of ideological Rorschach. Take sensitivity to initial conditions for example. Sobchack (1990) suggests that it implies "an embrace of *irresponsibility* in a world already beyond control." Hayles suggests it parallels a liberating "textual indeterminancy" in literary theory. Porush sees it as a disguise for oppressive domination, which can only be undone by the "true chaos" of stochastic randomness.

Although I welcome any attempt to illustrate the deeply cultural aspects of the "hard" sciences, I am wary of efforts to read cultural meanings directly from isolated texts or theories. When Sobchack cites Peitgen and Freeman in her condemnation of chaos theory as a denial of "the specificity of human embodiment and historical situation," I can't help thinking of Peitgen's mathematics course at UCSC, where he would comment on the reaction of German mathematicians to Nazi anti-semitism, or of Freeman's (1981) use of Martin Luther King in his discussion of chaos in neurophysiology. Or, for that matter, of Linda Garcia, a young woman of color who told me that fractal geometry was the main inspiration for her continued involvement in mathematics (Linda's *Fractal Explorer* is due to be published sometime this year). How can we critique the work of chaos theorists as lacking historical specificity and embodiment if we ignore their own histories and bodies?

But Sobchack is quite right when she suggests that there are general implications of chaos theory for culture at large. Essentially, my own "externalist" interpretation (keeping in mind that external/internal is a misleading division) is not that chaos re-emerged at this moment because it denies either recursive self-control or analog physicality, the two dimensions of holistic liberation. On the contrary, chaos re-emerged in science at the particular moment of the postmodern transition because at this point in history, those two dimensions ceased to be all-encompassing threats to the powers of social domination.

Instead, they became desired by it. But rather than forecasting the "nihilist" gloom that my radical holism friends accuse me of, I see this change as a new opportunity for positive political change.

In order to map out some historically specific, technically grounded approaches to the possibilities for liberatory practice in this postmodern chaos, I need to discuss two more areas of analysis. First, contrary to the expectations of holism advocates, both military and industrial/managerial institutions are quite immersed in this new organic, decentralized technological and philosophical practice. Second, it is important to understand that the *transitional postmodernism* starting around 1977, characterized by dualism reversal, gave way to a *stable postmodernism* around 1987, characterized by dualism synthesis. Following these two depressing portraits, I'll conclude this chapter with some uplifting, optimistic postmodern chaos stories.

3.7 Chaos as Control: simplicity in the military-industrial complex.

Over the years, I have often found myself arguing with holism advocates about the inherent morality they see in organic or humanist processes, and I usually toss out some quick examples from military or industrial management history. The reply is typically "Well sure, anything can be *abused.*" Like von Bertalanffy, they insist that "true" holism cannot be put to such uses.* Worse yet, my examples of establishment organicism are taken by others (eg Ferguson, Toffler) as a sign of positive change, proof that their "new consciousness" is taking hold at every level of society.

My reason for exploring the military and industrial/managerial uses of chaos is not to bash my radical friends for being too holistic, nor to suggest that either chaos theory or the military-industrial spheres are places of unmitigated oppression. To the contrary,

*Of course postmodernists also make these qualifications; I was once shocked to hear Gayatri Spivak state that "one cannot live deconstruction," thus (it seemed to me) ensuring a total lack of responsibility for any actions (as 'lived' theory) carried out under that label.

these contaminated spaces are some of my favorite sites for examining new political possibilities. But before we allow ourselves such optimistic ventures, we need to seriously examine how this theoretical and social terrain is being shaped in the postmodern era, and to what extent we can use these topological dynamics as new surfaces of political attraction.

Modernist researchers have often noted the parallels between the centralized hierarchies of military decision-making and organizational structure, and a similar centralized organization in military information technology (eg the "von Neumann architecture" of the digital computer discussed in chapter 1). The isomorphism has been analyzed from a wide variety of perspectives, including military historical development (Chapman 1987), history of cybernetics (Edwards 1985, 1988), bureaucratic defense management (Gibson 1986), and military social psychology (Gray 1989). These studies suggest both the construction of information technologies which conform to military organizational structure, and the development of defense operations which conform to the requirements of linear digital technology.[4] Critiques on the limitations of centralized information systems have become a key issue in many regional defense studies, and the notion of military force as a centralized organization is implicit throughout global arms stability research (Edmonds 1985). This analytic assumption of centralization is now on shaky ground. Since the emergence of postmodern information sciences, with their invigoration of nonlinear mathematics and parallel computation, the decentralized cybernetics has not only been applied to defense technology, but has also become a model for new organizational patterns and processes in many levels of the military structure, including the increasing decentralization of war itself. I hope that the description of this change will be useful not only to a general understanding of technosocial process, but also to researchers in the specific areas of conflict studies, arms control, and other efforts toward global peace.

The relation between the information sciences and military practice (my focus here will be the US military) must be seen as a two-way interaction. In the 1960s both assumed that decentralization is incompatible with efficient organization. In tandem with the information sciences, the US military has been steadily revising this assumption since the 1970s. Janowitz (1974) made a careful study of the history of hierarchical structure in the US military, and concluded that a shift towards more autonomous, localized command structures was occurring as a result of "complex technological innovations."

One of the first explicit attempts to move toward military applications from within the tradition of holistic cybernetics was that of James Miller, whose *Living Systems* (1978) drew on Wiener, von Bertalanffy and others. The title of his essay, "Potential Applications of a General Theory of Living Systems to the Study of Military Tactical Command and Control" - a title that might be rephrased "Applications of Life to Death" - is an oxymoron that underscores the tensions of transitional postmodernism's trope of reversal. A similar statement was made in a later military holism manifesto by Dik Gregory (1986) of the US Army Research Institute. A previous collaborator of Gordon Pask (featured back in chapter 2 as the conservative cyberneticist who found himself unhappily married to Bateson's radical holists), Gregory cites not only the cybernetic tradition of the 60s (noting both the disregard for analog representation and for recursion), but also the New Age zen physics of Zukav, and the latest on self-organizing systems philosophy from Varela and Maturana. He includes the standard holist history as well, condemning the centralist AI approach as "a philosophy that has dominated Western culture since the 18th century... with its emphasis on objectivity, causality, linearity, and it-referenced measurement" (pg 836). Gregory's goal is the development of self-organizing military technologies which can constitute "a dynamic 'living' system" - presumably resulting in static 'dying' people.

Practical application of holistic military philosophy has occurred at every scale. At the smallest level, individual skill organization has been modeled in terms of parallel processing systems; more recent research has explicitly utilized a neural network model (Schneider and Detweiler 1988). The linkage of individuals into decentralized military units has also been formally introduced under the rubric of "distributed decisionmaking" (Levis and Boettcher 1983, Adelman et al 1986, Saisi and Serfaty 1987). Technological models here may have come from distributed detection systems (also known as "distributed decision fusion") proposed for automated sensor systems (Tenney and Sandell 1981); but this genealogy is not entirely clear. The 'autonomous' professional discipline of organization theory is obviously pertinent here; I will go over some of these connections shortly in reference to managerial practice.

At the largest scale is the machine mediated battle organization of C3I, specified as the AirLand Battle Management system under DARPA's Strategic Computing Program. The formulation of operations doctrine for the AirLand Battle system was based in part on the use of "chaos" by the German Army in World War II, as described by Richey (1984). Here he notes that many Allied failures were due to conceptions of "battle fighting as a problem of imposing order on chaos," and that the German use of decentralized organization *(Auftragstaktik)* allowed them to "accept chaos as the natural substance of combat." This difference in the German acceptance of chaos was noted earlier in relation to their holistic romanticism (section 3.3).

The recent increase in military research on chaos theory indicates that the colloquial use of "chaos" from AirLand Battle doctrine has already started to dovetail with its technical sense in mathematics and information science. DARPA's 1988 strategic computing report lists 14 projects dealing directly with nonlinear dynamics. The agency recently proposed a $390 million, eight year neural net research program, with specific defense applications ranging from submarine sonar arrays to satellite surveillance

(Johnson 1988). Both analog and digital designs for self-organizing neural networks are funded, and North (1988) noted their possible application to organizational structures in C3I "command behavior analysis." The pre-chaos nonlinear dynamics of catastrophe theory was applied to military analysis in the early 80s (Dockery and Chiatti 1986). Application of both fractal modelling and chaotic dynamics to battlefield management has been explicitly mentioned by Gary Coe, chief of modeling and analysis of the Joint Staff in the Pentagon (Zorpette 1988).

Even from an internalist perspective, the technological side of these advancements may have dramatic social implications. The bottleneck of centralized information processing in the "Star Wars" strategic defense system has been a major source of criticism (Parnas 1985); a successful decentralized computer organization could reinvigorate such plans (as the new decentralist metaphor of "brilliant pebbles" has done for their physical organization). Several systems which have suffered under the lack of significant advancement in classical AI -- sonar discrimination, automatic target tracking, etc. -- have already shown improved success with neuromimetic designs (Mannion and Schwartz 1988, Roth 1989).

The most far-reaching changes would come from the large-scale C3I of the AirLand Battle system. Chapman (1987) describes the conflict between the desired doctrine of accepting "chaos as the natural substance of combat" and the predetermined, highly centralized and detailed hierarchy which linear digital systems have required. Edwards (1985) and Gray (1988) have detailed some of these relations between the centralized characteristics of linear digital systems and the centralized structures of AirLand Battle and other C3I projects. Nikutta (1987) points to several problems in nuclear escalation risks, crisis stability and political decision-making resulting from the inflexibility of these linear structures. If such decentralized military structures are successfully implemented, studies such as Nikutta's will require careful revision.

Adaptive decentralization for the global defense communications system is already under construction (DiSilvio and Edell 1988). In an area of more immediate usage, the frustration over low-intensity war has also been expressed in terms of the contradiction between linear hierarchical order promoted by current technology and the "chaos" of these dynamic, self-organized conflicts (Dean 1986). One area of semantic convergence is in the frequent metaphor of "brush fire wars in the Third World" (Klare 1981, pg 69); mathematical models for brush fires have become a featured example for chaos theory (Bak et al 1990). In a familiar dialectic, technology must adapt as warfare itself becomes increasingly decentralized, while conversely, decentralized technology makes such wars more possible.

Both managerial and technical internalists see such loose metaphorical parallels such as 'brush fire' as irrelevant, and concentrate on the 'hard facts' of technology and structure. They agree that organizational sciences, like any other science, build progressive knowledge over the years, which may, in combination with "external" factors (such as a new economic need or new computing device) eventually lead to changes such as decentralization. They differ in their causal directions, with one side seeing organizational decentralization from decentralized technology, and the other the reverse. Markus and Robey (1988) provide an excellent review of this literature, and note that after three decades of study, neither causal direction has shown a balance of evidence tipped in its favor. They recommend instead an "emergent perspective," which

> between technology and human actors in organizations. Central to the emergent perspective is the social meaning ascribed to information technology. This perspective accounts for conflicting research findings about impacts by demonstrating the different meanings that the same technology acquires in different social settings. (pg 595)

The particular "social meaning ascribed to information technology" that I am making a case for here is that of an enormous cultural zeitgeist, but its analytic usefulness is only in the local particulars of its expression. While military organization was able to

make direct use of the cybernetic holism tradition, this path was still too tainted for many management science writers. One exception was Daft and MacIntosh (1978), who argued that the analog encoding of information in facial and vocal expressions was demonstrated as a superior modality for dealing with "unanalyzable, nonroutine tasks," and -- as in the essays of Dewdney and many other cybernetic claims of this time -- digital representation was seen as being more limited. These pro-analog views are more prevalent in formal studies from human factors engineering and ergonomics. Moses (1978) for example, makes similar observations to Daft and MacIntosh, and used video tape as a way of bringing this communication into technological mediation and control.

Moses also used his video system to increase employee feedback to management. Several different types of recursion were introduced into management science at this time, particularly in the framework of worker participation schemes (recursive in the sense that it involves worker-controlled work). This change is much more commonly recognized, and has a history in formal human factors engineering that dates back to the discipline's formation as "industrial psychology" in the 1920s. The recent acceleration in this approach has been the subject of much debate in the "labor process" literature (see Knight 1985 for an extensive review). At the center of this discourse is the postmodern crisis of humanism: how can we discuss autonomy or self-control as a form of oppression if (under humanist views) that is the very definition of freedom?

Analog representation has often entered this debate under notions of "tacit knowledge" -- typically presented as a collection of skills and information that maintain shop floor control due to their informal nature (Manwaring and Woods, 1985). Not only do such analyses tend to ignore the use of analog representation by postmodern management science, but they can also overlook the ways in which self-control becomes self-exploitation. In Eskew and Riche (1982) for example, personality tests were correlated with error scores for self-paced v.s. externally paced tasks. This selective use of worker

self-control indicates that it is not simply a general liberatory shift, but instead a new feature which maps individuals into the labor process in ways which are optimal for the owners. Hacker (1979) demonstrated this selective mapping for race and sex stratification. In her study the introduction of new information technology at AT&T allowed for greater skill utilization and autonomy, but was applied in such a way that minorities and women received the benefits least and suffered the greatest occupational displacement.

As in the case of technical and military holism, these techniques of capitalist holism began to emerge in the late 1970s. All of these disciplinary spheres felt the strain of a sudden reversal, and although some military researchers (who may have been less subject to critiques of flakyness or impracticality) seemed quite oblivious, the managerial writings are cautiously subdued and rarely have a manifesto quality. This reservation was altered, however, in the late 1980s -- I'll stick to 1987 for consistency -- by the change from this transitional postmodernism to a new stable postmodernism. In the previous chapter I outlined the ways in which four scientific disciplines, all making use of information theoretics, expressed similar reversals in their conceptualizations of both analog-digital and self-referential processes during the postmodernism transition. In the next section we will look at the same four disciplines as they move from the transitional trope of reversal to the stable trope of synthesis. As in the previous chapter, these same changes can be seen in the semiotics of certain segments of popular culture. Both military and managerial institutions have also followed this route to postmodern stability.

3.8 Stable Postmodernism -- technical harmony

The four different disciplines examined in the historical portrait of the last chapter were mathematics, machine intelligence, visual neurobiology, and cerebral lateralization. In all four areas, we saw a similar transition. The emphasis changed from digital to ana-

log and from linear hierarchy to non-linear decentralization. This section will briefly describe a second change in these same disciplines to an analog-digital synthesis, and centralization-decentralization synthesis. As in the last chapter, this will be compared to similar changes in popular culture. I have termed this "stable postmodernism" because it resolves the tensions of a sharp reversal in these areas. Similarly, military and managerial institutions moved toward this dualism synthesis, and, as we will see, they also were relieved of the embarrassment of reversed dichotomies.

When we last left mathematics, it had moved from the linear programming and formal logic of the 1960s to the fractals and dynamical chaos of the 1970s. In the late 1980s these two approaches were brought together. This was nicely illustrated by the "multifractal" approach initiated by Uriel Frisch (Nice Observatory) and Giorgio Parisi (University of Rome) in 1985. Multifractals are shapes which cannot be characterized by a single fractal dimension. Since they have multiple dimension measures attributed to them, some of these can be whole numbers. Thus multifractals can incorporate *both* fractal and Euclidian structures. A similar fractal-Euclidian synthesis has developed in the use of Michael Barnsley's Iterated Function Systems (IFS). The mathematical basis for using the IFS in a general synthetic approach to images is the "collage theorem," first proposed in 1985. By 1987 word was out that this might lead to a general system for image compression (transmit algorithms for producing the picture instead of the picture itself) and perhaps even image recognition, although the commercial possibilities here (Barnsley is now part of Iterated Systems Incorporated) have tended to quiet the information available on this latter application.

The dynamical counterpart to this hybridization or synthesis would be a system which allows behavior to be both periodic and aperiodic. This has not happened, nor do I expect it to happen, and it is a good way of reminding myself that the history I present is just a cartoon image, with much lost to its simplification. There is, however, a new

concentration on the harmony of other opposites in dynamics. This comes from the discourse of "self-organized criticality," where chaos is seen as a compromise between random or noise-amplifying forces and periodic or noise-suppressing forces. I will go into this in more depth in the next chapter.

In machine intelligence, we saw the postmodern transition from linear digital hierarchy in the 1960s to both decentralization and new analog neural nets in the late 1970s. By 1987 many researchers decided that the difficulity of nonlinearity, despite the new knowledge rising from chaos theory, was still too great for a pure analog approach, and that analog and digital would need to work together in new hybrid machines. Marvin Minsky, for example, had trashed holism in his modernist text "perceptrons," and had valorized it in his transitional postmodernist text *Society of Mind*. In his stable postmodern essay of 1988, he suggested that the "Society of Mind" approach would incorporate analog neural nets as the individual "agents" of his AI society, and that digital algorithms would provide its governing structure.

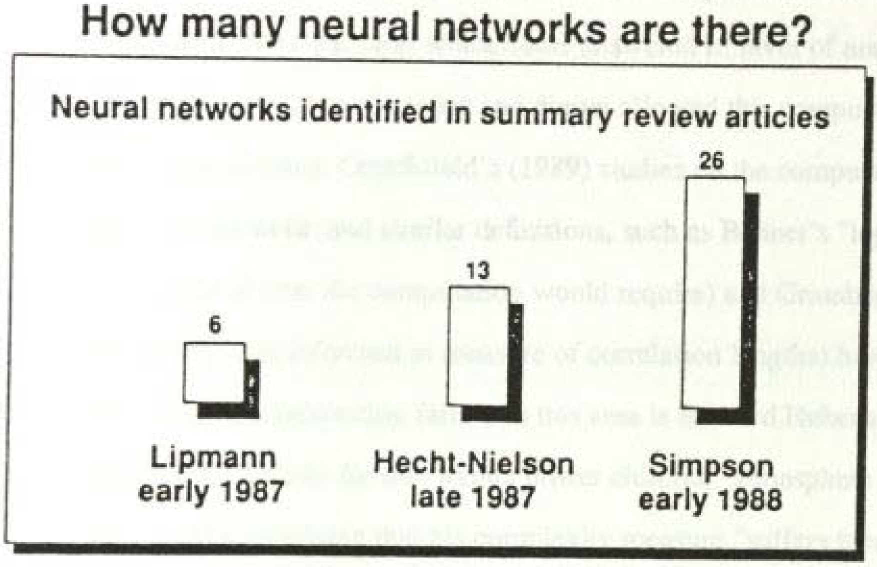
As in the case of Minsky's previous conversion, this "new" concept of holism-reductionism harmony had already been formulated in the work of others. Pollack (1989) differentiates between "the *old* new connectionism, circa 1980-1985" and "the *new* new connectionism" on this basis, noting the crucial addition of digital representation to neural nets in "semantically interpretable higher-order elements" (e.g. Hinton 1986). The reverse adaptation can also be seen in the work of Stephen Omohundro. In a widely circulated technical report of 1987 he described some important innovations for algorithms in digital centralized computers which could emulate neural network behavior. Equivalences between recursion in both analog and digital systems were also approached at this time (eg Touretzky 1986), and later commercial production of the hardware that could support such hybrids (Electronic Design 1989) also occurred. Also appearing at this time were neural nets based on a harmony theory similar to Bak's self-

organized criticality. Whereas modernist networks were based on competition, and transitional postmodernist networks exploited formal systems of cooperation, these stable postmodernist neural nets used a balance of cooperation and competition to achieve their tasks (Maren 1990). This change from the transitional trope of reversal to the stable trope of synthesis or harmony allows a resolution of previous tensions, thus opening a new acceptability. Harston and Maren (1990) cite an exponential rise in the number of neural nets projects starting in 1987 (fig 3.6).

Analog-digital synthesis in more banal computing machines had been suggested by Rob Shaw's Cabal in a 1981 NSF grant proposal, but the idea was premature and the grant was rejected, although they did receive NSF support for work on their analog computer. Current NSF grant directories specifically mention analog-digital hybrids as an area of interest. Much of the theoretical work in this new synthesis goes under the the rubric of computational dynamics, a title which not only emphasized the new fusion of analog and digital computation, but could also serve as a respectable sounding alias for "chaos."

Reassessment of the analog optimism from transitional postmodern cybernetics was an important part of this new effort toward harmony. While many transitional postmodern researchers saw analog computation as uncharted territory, a potentially utopic space where physical dynamics could beat a Turing machine, the new stable postmodern theories viewed analog and digital as equivalent representational forms. The most formal recognition for this equivalence was in the work of Blum, Shub and Smale (1989), which developed a system of mathematics that could show limitations for analog computation which were isomorphic to the undecidablilty limitations of Turing machines. Similar results were reached through work in symbolic logic by Rubel (1989), who used this to critique the earlier claims of analog superiority by Vergis et al.

Figure 3.6: Exponential rise in neural nets, 1987



The number of neural networks identified in comprehensive review articles which appeared between 1987 and 1988 [Lippman, 1987; Hecht-Nielson, 1988; Simpson, 1988].

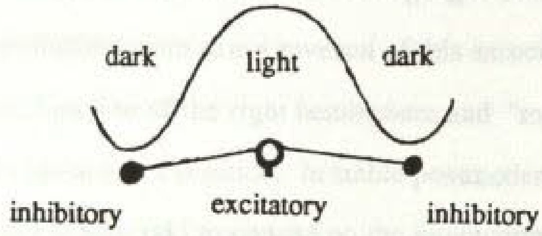
From Maren et al (1990) fig 2.1

Also carrying this new egalitarian view was the formalization of complexity. In an philosophic precursor to the formal studies, Foo and Zeigler (1985) suggest that "by introducing a computational component into system complexity theory... the conflict between holistic and reductionist views of systems can be partially reconciled." Recall from section 3.4 that complexity definitions had changed from Kolmogorov's modernist randomness to new notions based on difficulty of computation. In transitional postmodernism the informal nature of these definitions left the computational status of analog systems an open question (a question which some answered in favor of analog). In stable postmodernism the equivalence of analog and digital allowed this computational complexity to be formally defined. Crutchfield's (1989) studies on the computability of time series is the best of this work, and similar definitions, such as Bennet's "logical depth" (based on the amount of time the computation would require) and Grassberger's "self-generated complexity" (an information measure of correlation lengths) have worked toward this direction. An interesting failure in this area is Bernard Huberman's (1986) attempt. Recalling his distaste for the "vague flower children" atmosphere of the Chaos Cabal's lab, it is not be surprising that his complexity measure "suffers from excessive model-dependance in that it assumes an underlying hierarchical structure in the system" (Bohr 1989, pg 11). In stable postmodernism centralists need not fear that holism rules, but their reductionism alone will not suffice.

In visual neurobiology, we moved from the 60s reductionist feature extraction hierarchy of Hubel and Weisel to the 70s holistic fourier transform model of DeValois. But the experiments which had supported this view of global spatial frequency detection did not negate Hubel and Weisel's results, and following some debate a synthesis was proposed (Mackay 1981). The model finally adopted used the Gabor transform, a combination of local and global information extraction (fig 3.7) which had been developed in early communication theory, prior to the polarizing split of the 1960s (Gabor 1946).

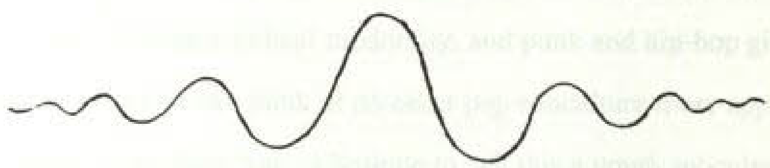
Figure 3.7: Models of visual cortex processing

Hubel and Wiesel model: lateral inhibition in retina isolates local points. Cortical layers combine points > lines > simple shapes > complex shapes > "grandmother cell" (reductionist processing).



DeValios and Albrecht model: lateral inhibition in retina creates fourier transform. Cortical layers combine global spatial frequencies in holistic processing.

Daugman model: lateral inhibition in retina creates Gabor transform. Cortical layers combine global spatial frequencies with local points (reductionism-holism synthesis).



Empirical confirmation soon followed (Daugman 1984).

In cerebral lateralization, modernist theories suggested that the digital left hemisphere was mathematical and male, and that the analog right hemisphere was artistic and female. Transitional postmodernism saw a reversal of this association, with mathematics as an imagerial, holistic function of the right hemisphere and "man the hunter" preferring spatial mapping in his neural evolution. In stable postmodern lateralization, mathematical superiority is now said to depend on the interaction between both hemispheres, again leaving room for male superiority through studies reporting sex differences in interhemispheric information transfer (first described in De Lacoste-Utamsing and Holloway 1982; see Bradshaw 1989 for review of recent research).

In all four disciplines, information processing shifted from the holism reversal of the postmodern transition to a new holism-reductionism synthesis. As in the case of the previous two transitions, this paradigm not only extends across many sciences, but also can be seen as part of a larger cultural zeitgeist.

3.9 Stable Postmodernism: social harmony

If hippies epitomize radical modernity, and punk and hip-hop give us transitional postmodernism, then I can think of no other pop subculture more appropriate to stable postmodernism than New Age. I hesitate to call this a youth subculture, since most of its members are not very young, but in some ways it fetishizes youthfulness even more than its predecessors. There are some emerging pop subcultures of this era that really are created by youths, as I will point out in the last section of this chapter, but here I want to use New Age since it emphasizes the problematic politics of holism-reductionism synthesis.

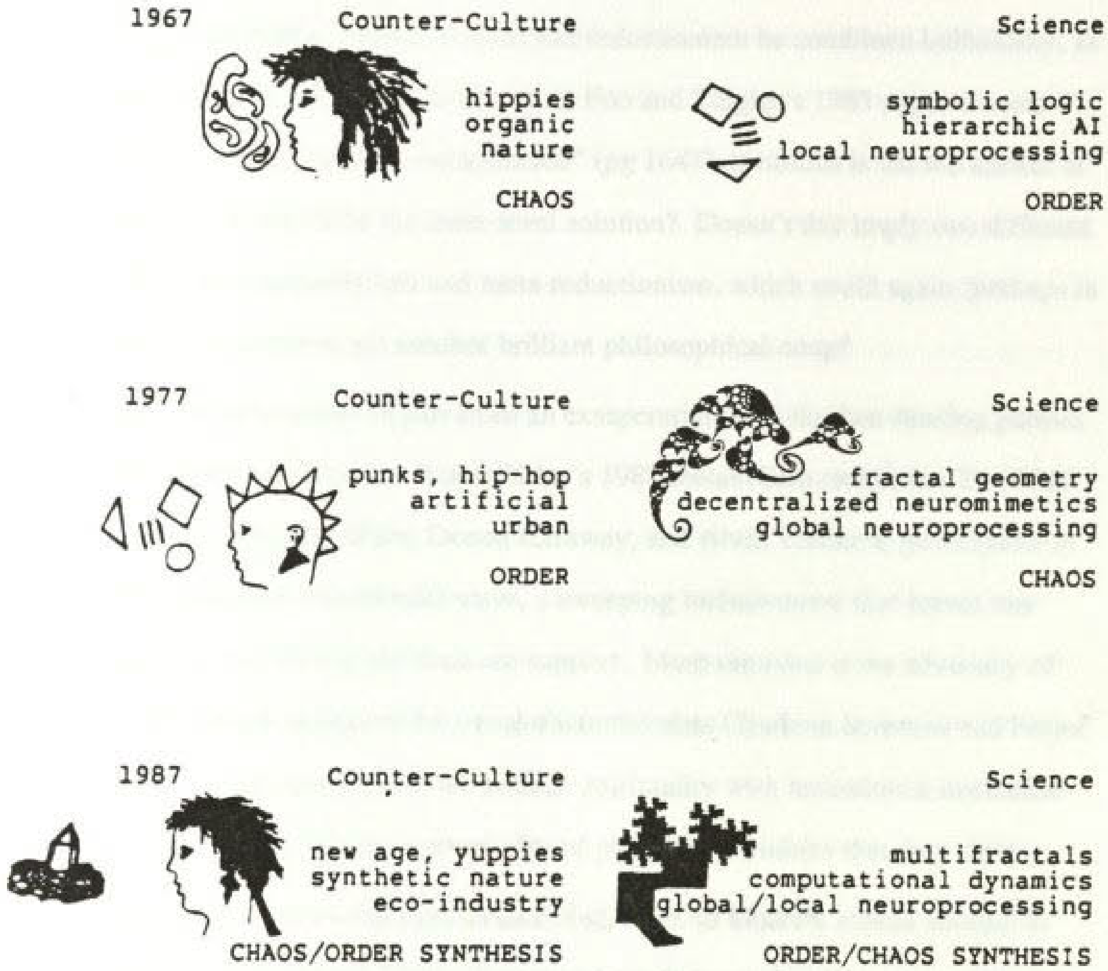
Like hippy and punk rock enthusiasts, New Agers are primarily white and middle class, and the semiotics of their subculture often concern this ethnic/class identity. Hippy

material culture could often be read as an avoidance of whiteness, a transformation into imagined Native Americans or orientalist holy beggars. For hippies artificial (eg Euclidian shapes, synthetics) signified White, and natural (chaotic shapes, organic materials) filled in this blank with a more moral identity. Punk subculture claimed the blankness as its own, using artificial and urban-associated materials to signify both their acceptance of their ethnic identity and a refusal to ignore its ugliness. New Age members, like the cybernetic engineers of their era, solve this problem of identity conflict neither by taking one side or the other, but by harmonious synthesis.

The symbol which best portrays this hybrid identity is the crystal embedded in unpolished rock, a common motif in New Age fashion, art and literature. Like multifractals, these objects are both Euclidian and fractal, both orderly and chaotic, and carry the paradoxical message that something can be both natural and artificial. In New Age subculture whiteness is just one of many ethnicities -- one which happens to have an odd association with artificiality, but that too is natural. Hence the "solution" of identity conflict here is in part the elimination of identity; not surprisingly New Age members can "channel" through cultures (even those long gone) in ways which make the most wanna-be of hippies look like white pride advocates.

The synthesis of artificial and natural is also conveyed in New Age music, which typically uses artificial (ie electronic) instruments to make natural sounds. But the natural sounds are themselves supposed to reflect only the soothing harmonious essence of nature, the "music of the spheres," and therefore have an ethereal, unworldly character to them. Another popular symbol among New Age participants is the yin-yang sign, which has a history of orentalist interpretations that has shown great flexibility. In the 1960s the yin-yang was said to represent holism, the true unity that lies beyond dualist illusions of day and night, hot and cold, etc.. In New Age subculture the same symbol is used to represent the unity of holism and reductionism. Fig 3.8 summarizes this

Figure 3.8: Science and popular culture, 1967 - 1977 - 1987



comparison of youth subcultures and science in the three historical moments I have outlined.

While this synthesis solves many of the tensions that the transitional reversal posed, justifying the lifestyles of thousands of ex-hippie computer programmers, it presents some conceptual problems. Should holism and reductionism be combined holistically, as in the yin-yang sign, or reductionistically, as in Foo and Zeigler's 1985 paper on complexity: "holism = reductionism + computation" (pg 164)? If holism is not the answer at the first level, why should it be the meta-level solution? Doesn't this imply two different methods of synthesis, meta-holism and meta-reductionism, which could again (perhaps in 1997) be brought together in yet another brilliant philosophical coup?

My cynicism here comes in part from an exasperation with the free-floating politics that this metaholism has allowed. Riane Eisler's 1987 metaholism manifesto, *The Chalice and the Blade,* cites Karl Marx, Donna Haraway, and Alvin Toffler as participants in her "glyanic" (gynic/andro synthesis) wave, a sweeping inclusiveness that leaves one wondering if there is anything she does *not* support. More ominous is the advocacy of prayer in public schools suggested by metaholism theorists Charlene Spretnak and Fritjof Capra. While this may indeed combine holistic spirituality with reductionist institutionalization, it hardly seems like the cutting edge of progressive politics that they claim.

As in the case of holism pure and unmodified, I see no inherent ethical content to holism-reductionism synthesis. Eisler, for example, points out that the notions of both patriarchy and matriarchy suggest domination. In her utopic origin story we were originally in a "glyanic" state of "partnership" rule. But it is hard to see how this notion of partnership is inherently more liberating; it recalls Rich's compulsory heterosexuality and bourgeois ideals of family norms (see pg 39 of Eisler's text). It also includes a sense of social "evolution" with a deterministic flavor that uncomfortably parallels sociobiology. In H. Pagels's popular science text, centered around the development of complexity

definitions from a synthesis of analog and digital computation, he begins with a long story about the failure of cultural holism in the 1960s, and his hopes that in this era we would see a "new synthesis" which "represents a compromise between the hard-core sociobiological outlook and the more traditional view that sees cultural and social factors as... determinants of human behavior" (pg 48). Robert Trivers, well known for his unrelenting biological determinism, was recently a featured speaker at a New Age colloquium at UCSC, where he discussed drugs and the evolution of consciousness.

Like the holism of transitional postmodernity, this holism-reductionism synthesis is also hard at work in military and industrial applications. Overall, the history of decentralization in U.S. military organization appears to have followed the same general pattern as that of information technology, with an initial enthusiasm for holism as a complete solution, and later compromise with a holism-reductionism synthesis. In the work of Gregory (1980, 1986) for example, a clear dualist argument is made in terms of the failures produced by previous concentration on linear hierarchical information systems, and the military hopes for success through nonlinear recursive networks. More recently, however, military researchers have expressed a greater interest in holism-reductionism synthesis. Robert Smithson of Lockheed, for example, recently suggested that the ultimate defense computing system would "operate in a continuum of modes ranging from analog to digital, and from network to sequential processor" with an optimum combination sought for each problem (Stoddard 1990).

While the transitional postmodern manifestos of holism were somewhat unnerving to both military and industrial readers, the new holism-reductionism synthesis resolves this tension, resulting in an invasion of "chaos" discourse at both popular and institutional locations. 1987 saw the best-selling publications of not only Gleick's popular *Chaos - making of a new science,* but also Tom Peter's business management text, *Thriving on Chaos*. While Peter's previous *In Search of Excellence* looked for stability in

industrial order, by 1987 it was more important to look for stability in chaos. This was only an intuitive connection, with "chaos" as a synonym for unpredictability or disorder of any kind, but it carried the idea of uncertainty as a resource rather than deficit, and of self-organizing systems as productive, effective managerial designs.

In the 1980s the term "chaos" also appeared as a popular term in the computer tech end of business, as exemplified by MIT's "chaosnet" and Jerry Pournell's "Computing at Chaos Manor" column in Byte magazine. These have only a metaphorical relation to mathematical chaos theory, using the term to signify a sense of productivity in the disorder associated with both social and technical aspects of decentralized computing (eg the hacker communities). Mathematical chaos theory is used more explicitly (though still informally) in some of the more popular management/organization literature (e.g. Goldstein 1988). Here it also converges with New Age pop culture (e.g. Weisbord 1987), drawing on Alvin Toffler's futurist school of metaholism (which Toffler terms "wholism"). In formal, quantitative business management studies chaos theory and its related systems are featured in areas such as predictive methods for stock market fluctuations (Lorenz 1987), managerial decision making (Rasmussen and Mosekilde 1989), job scheduling and control systems (Schneider and Detweiler 1988), and machine tool control (Grabec 1986).

In the metaholism analysis this fusion of self-control with hierarchy, and of physical dynamics with symbolic structures, will automatically lead to a social utopia. In the modernist analysis, such as that of Herbert Marcuse or Harry Braverman, the added humanism and organicism is a sugar coating for the bitter pill of capitalist oppression. From my postmodernist view, humanism and organicism are themselves possible sites of both oppression and resistance, as are their opposites (imposed control and artificiality). For example, in Aihwa Ong's description of Malay women in multinational assembly line work, neither the indigenous village hierarchy nor the capitalist individualism of

factory life are seen as inherently liberating or inherently oppressive, and the kinds of identities and forms of resistance that these women do, quite brilliantly, create for their own benefit are more dynamic shifts through multiple cultural positions than any single static locating of utopic goals. Spirit possession, for example, is traditionally a sign of Natural female weakness, and acts as a guard against assertive behavior by young unmarried women. In the context of the assembly line, this became a covert method of retaliation for over work, underpay and grueling supervision. It was not explicitly planned or overtly self-conscious, but it was also used by women who were not of the "natural" age for spirit possession. At times these episodes closed down entire factories.

I think Eisler is correct in her suggestion of cohesive historical eras, but incorrect in assigning a particular moral designation to them. Indeed, it seems ironic that she should make such heavy use of cultural anthropology without adopting its most valuable theoretic stance, cultural relativity. Ong's ethnographic work reminds us that relativity is not incompatible with social critique and political progress, and her work can be used as a model for understanding the kinds of larger histories that Eisler and I are both interested in. Having used this section to make my case against the holism-reductionism synthesis of stable postmodernity as an *inherently* liberating state, the next section will conclude this chapter with some examples of locations within this cultural zeitgeist where resistance and rebellion can be found.

3.10 Political Resistance in Stable Postmodernism

In the last section we examined the political failings of metaholism theory, the military industrial complex, and popular culture in the era of stable postmodernity. Here we will look at discuss political success in these same three areas, focusing on the examples of metaholism theorist Ralph Abraham, Los Alamos physicist Gottfried Mayer-Kress, and Rap artist Queen Latifa.

The metaholism I've used Eisler to represent has adherents which stretch from hard-core technophiles, who see human intervention as a gesture of nostalgic generousity, to organic purists doped with a touch of metal. There are examples at all locations of this spectrum, from the politics of hacker communities to video technology in indigenous Amazon rights groups, which illustrate some of the radical possibilities in concrete, historically specific ways. While the radical modernists of the 60s saw the problems of human history as originating in the fall from an authentic, holistic utopia, Eisler's metaholism claims an authentic holism-reductionism synthesis as her ancient utopia. From my own stance, both of these viewpoints suffer from notions of the "authentic," and the radical aspects of stable postmodernism are, I think, generally those which use combinations of holism and reductionism to contradict or interrogate authenticity rather than harmoniously support it.

The idea of virtual reality or cyberspace, of communities and sensory experiences which are artificially made to order, is often touted as a cutting edge in current legitimations of the inauthentic. I've already discussed some of the examples of displacement of "natural" gender roles in virtual reality back in chapter 1. The politics of cyberspace is currently a hot topic, and needs no promotion from me; if anything it could probably use a dose of critical cynicism. While cyberspace offers virtual materiality (such as Toffoli's "computronium"), things which don't really exist but seem to, there is another, less explored phenomenon of stable postmodernism we might call material virtuality: things which don't seem to exist but really do. In nanotechnology, for example, what appears to be merely a collection of tiny machines can have the real physical properties of a complex chemical reactant, or even more sophisticated activities. "Invisible technologies," like the stealth bombers, and "smart materials," which change shape or physical properties on command, are also in this category. Pop examples of material virtuality include the children's "transformer" toys, which metamorphose from cars to robots (and

from cartoon to consumer item).

With all these locations to choose from, it may be a surprise that I've returned to Eisler's particular metaholism as a place to find radical politics. One reason is that at times I hesitate to critique anyone who takes a strong stance against racism, sexism, and class oppression. We desperately need a united front in these battles, and now that I've made my objections I want to look for areas of alliance. The other reason is that one such area is easily accessible to me, and has the added attraction of an intimate involvement with mathematical chaos. This is the metaholism of my mathematics advisor, Ralph Abraham.

I am not describing Ralph's work to represent a new improved version of Eisler. Ralph both inspired parts of her work -- his dynamical systems theory is featured by Eisler as the basis for causal relations in her historical account -- and was inspired by it. His own histories and politics are generally in accord with her framework. What makes his metaholism exemplary in my mind is not so much the problems it solves as the way it gets him into trouble.

Ralph occasionally prefaces his work with autobiographical statements; these usually center on his completion of a now classic text of dynamics, *Foundations of Mechanics,* and his sudden awakening to the 60s. Ralph became notorious (or celebrated depending on who you talk to) for his illegitimate mixture of hippie politics with his position as a mathematics professional and tenured professor. Following a brief stint as professional gambler (at one time attempting to devise an analog computer that could beat the "wheel of fortune" casino game), he returned to mathematics, just in time to provide some needed support to Rob Shaw's chaos cabal.

While some of Ralph's activities keep him in the harmony and hot tub circuit, his interventions in academic and professional circles often put him in risky or challenging

circumstances that bring a radical edge to his metaholist stance. For example, when he casually mentioned to members of the UCSC math board that he was thinking about giving a course on women in mathematics, he was met with surprising opposition.

> I was told "Oh, they'll never let you do that." It was at that point that I actually made a commitment to hold the course. I didn't think "they" were *letting* me do anything.

Ralph's feminist perspective is central to his connection with Eisler's politics, but it has deep personal ties for him as well. I once asked him about his early influences, and he said that his mother's expertise in repairing household appliances, and the sorority meetings at her home, where women would have animated discussions on the intellectual topics of the day, both made big impressions on him. He describes his own identity as "a lesbian bisexual celibate," and his account of the ancient partnership utopia strongly contrasts with Eisler's in that sexual diversity, rather than harmonious heterosexuality, is seen as the key to ideal metaholistic society.

Generally, feminism at UCSC is not so controversial, and inserting it into the metaholism framework of "partnership" often seems to back away from its more radical implications. But Ralph's attempt to bring about this synthesis in the practice of academic mathematics forces some not-so-harmonious interactions. Not only has this put some of his work at odds with the university administration, but even in his own community of metaholism advocates, where most promote a synthesis of male artificiality with female naturalness, Ralph's notions of feminist mathematics do not fare well.

These difficulties are all the more exacerbated when it comes to race and ethnicity. The "General Evolution Research Group" Ralph, Eisler and others founded was meant to focus their synthesis between universal systems theory and universal cultural theory. But at odds with this universalism is Ralph's background in the cultural specificity of anti-

racism movements.

> I was old enough during WWII to be deeply affected by the holocaust, even though I didn't know "Jewish" till I went away to college (diversity in Vermont means what kind of cows you have). In 1968 I woke up to political activity, re Vietnam and Black rights. That was the year I met Bill Moore, a friend of the Panthers, and together we tried to create college seven, the college of Malcolm X. This went on for about 6 months in 68-69, after that I was mainly involved in trying to survive the backlash -- from the campus, the FBI, the local right, etc. I fled the country in 1971, and stayed away until it cooled down. (personal communication)

While Ralph's explicit social theory sticks to Eisler's notion that human history shows uniform simultaneous changes across the globe, his historical work contradicts this claim. His history of mathematics, for example, often highlights elements of non-European mathematical contributions, citing Near East, Far East, African, and even Native American connections.

This is not to say that these contradictions only work in a negative fashion, as if they were merely occasional stains on his essentialist purity. For example, in a review (1989, co-written with Francisco Varela) of Steven Hawking's work, the status of Hawking's physical disability is changed from the often offensive portrait of disparaged unnaturality (e.g. Chris Shaw's metaholism sci-fi film *Split)* to a triumph of physical challenge.

> Hawking's book, *A Brief History of Time,* broadcasts not his theories but his self: a handicapped genius, an ephemeral mind caged in a Star Wars wheel chair, yet soaring into the skies of abstraction to explore the cosmos. ...As we have always had serious doubts about the Big Bang hypothesis and its Big Crunch implication yet not had the muscle to condemn it, this post-modern Dedaelus is our planetary hero.

It is at these moments, when Ralph offers his own work as "just another mythology, like the rest of modern science," that metaholism shows its possibilities as a radical practice.

Since I've emphasized the difficulty of metaholism as a radical position, despite its glowing popular promotions, it is fitting that my next locus of analysis is located in the heart of military technology, which is not the recipient of popular promotions (although it

glows in a more literal sense). In the work of Gottfried Mayer-Kress at Los Alamos Labs, the famous US nuclear weapons facility, there is a discourse and activism which opens some surprising political possibilities.

The paradox of Mayer-Kress is reflected in a June 1989 *Scientific American* news brief on his work, titled "Pentagon hawks take heed of a dove's chaotic theories." The article described Gottfried's work on chaos theory as a tool in conflict resolution, warning of impending military escalations, and it emphasized the irony of pentagon interest in his work (noting that the pentagon is also interested in modeling warfighting scenarios). In response to this Mayer-Kress was quoted as saying, "We all want the same thing, to avoid war." This optimism is not unusual for Gottfried, and is the source of frequent accusations of naiveté. As a way of giving a more detailed perspective on his work, I recently asked him for a virtual interview over electronic mail, and obtained the following replies.

My first question was on the origins of his political orientation.

> Well, I grew up in an authoritarian catholic environment where I was an altar boy under a tyrant priest. I talked back at him and got punished, but had my first strong "question authority" experience when I was around 10-12. I had no problem resisting the strong social pressure from my motor-bike friends to drink and smoke. At the same time I had their respect for what I was doing in the group. When I was about 15 I learned that a cousin of mine had started prostituting, and against the strong resistance of my parents I hitch-hiked to the big city and tried to find her without success. I had the experience to follow my own sense for what is right against the strong opposition of my family and peers.

This desire to "follow my own sense for what is right" led to Gottfried's political work in his native Germany, previous to his postdoctoral position at Los Alamos.

> I was a supporter of the green party and involved in many of their actions (anti nuclear/environmental/peace actions etc), but I never was a person who would enjoy their party and strategy discussions/fights. I was a member, however of several ecological/peace groups and committees, and before I left I was the head of the local branch of the BUND, the Bund fuer Umwelt- und Naturschutz Deutschland

While still in Germany, Gottfried met the Chaos Cabal's Doyne Farmer, then at Los Alamos, and was impressed with his mathematical work as well as his politics and creative outlook. When the opportunity arose to work with Farmer (as well as with one of the most powerful computing systems in the world), Gottfried took the job. Although they were in the supposedly non-defense, pure theory section of the lab, both were well aware of the likelihood that their work would eventually be applied in defense systems. While Gottfried's social forecasting studies grew out of this concern, it was by no means his only response. The most impressive was his activist work in the Santa Fe peace groups, which included some risk to his own career since he was protesting at the lab where he was employed.

> We handed out leaflets on Nagasaki day 1984 and got chased away by lab security, and we had regular meetings in Los Alamos to hand out leaflets from a fenced off area near the fire station ("the mud pit"). We got mixed responses from lab people, some very positive ("I'm on your side but I work from within") up to more negative comments. Los Alamos Women for Peace hosted a group of Japanese survivors of the atomic bombing, and they asked me to show them the lab. I felt funny as a German, showing them the US center of atomic weapons research, and I volunteered to talk to the public affairs office. I got a very negative response from them, and finally arranged a guided tour through the science museum. Here the guide started off with solar energy research in Los Alamos until I reminded him that the visitors were also interested in the (dominant) historical section of the museum, but by then he had already almost run out of time, so he rushed by the replicas of Little Boy and Fat Man, that typically grandmas use as a backdrop for pictures of their grand children.

This section of Gottfried's narrative gives a glimpse at not only his non-naive political commitment, but also a willingness to live with contradiction, one which can be found in his technical work as well. Although the idea of mathematical techniques for social forecasting recalls dystopian nightmares of technocracy, his first attempt (Mayer-Kress and Saperstein 1988) implied a strong critique of Ronald Reagan's Strategic Defense Initiative (the model showing high probability for an arms race of both offensive missiles and antimissile defenses). His work is by no means restricted to oppositional uses however, and his publications typically portray the kind of middle-ground

sensibility quoted in the *Scientific American* article.

A 1989 Los Alamos technical report by Gottfried illustrates some of these contradictory characteristics. His first remark on political control sounds ominously elitist, recommending "the old philosophical idea of having the wisest people lead the nations." This is a reference to computer wisdom however, and is not offered in the spirit of von Neumann's reductionist technocratic control, but is an attempt to argue in favor of the incorporation of holistic processes and concepts (via computational dynamics) to a reductionist-inclined audience, accustomed to verbal arguments based on game theory and linear cause-effect relations. Gottfried carefully presents examples of failures of US arms control due to "the static and linear paradigm of a traditional approach," and suggests ways that the chaos-based models could provide new possibilities for cooperative behavior.

The suggested transformation is not presented as a reversal of previous doctrine, but as a combination or hybrid with greater capabilities than either alone. "The synthesis of game theoretic and dynamical models might lead to considerable improvements including both explicit and implicit decision-making processes." Another hybrid he offers is by way of an analogy to chess games. Predicting that the future grandmasters will be neither machines nor humans, but teams based on their mutual support, Gottfried stakes a technical claim for "computer-aided politics." Finally, there is a synthesis in his presentation of deterministic chaos, which is used both to attract the von Neumann types, who like the notion of control suggested by determinism, while also making room for a new flexibility and acknowledgement of predictive limitations.

> In the theory of international politics one finds the rule that... any political situation can lead to different futures. An analogous situation is observed in nonlinear dynamical systems: If the system is in a chaotic state, the basically identical initial conditions can lead to completely different future development (pg 4).

Gottfried's syntheses are not shams or misleading cover-ups; his willingness to both critique the power elite and work with them reflects some of his deeply held convictions. By striving for harmony in hard places he has opened the way to an impure, polluted politics, one which operates in the belly of the beast. If there is an ideological forefront in stable postmodernism, it is in just such contaminated spaces.

Finally, there are also places in popular culture where radical agendas of this era have recently fomented. While New Age subculture certainly has some local points of interest (see work by Joe Dumit at the UCSC History of Consciousness board), as a whole it has some of the most offending instances of harmonic political impotence. As an alternative instance of popular subculture which both reflects stable postmodernism and has a radical content, we will look at the work of rap musician Queen Latifah (Smith 1990).

Dana Owens was eight when her Muslim cousin nicknamed her Latifah, which means "sensitive" in Arabic. Raised in the projects of East Newark, her training included singing in the Shiloh Baptist Church choir and rapping in the high school locker room. In her first year at a community college, with plans of going into broadcast journalism, one of Latifah's friends passed a demo of her song "Princess of the Posse" through the professional rap circuit. The song eventually made its way to Tommy Boy Music's president, who signed her on for her first single.

Tommy Boy Music also represents Digital Underground, Stetsasonic, and Information Society; groups whose titles signify hip-hop's subversive comfort with the artificiality of high tech identities. At the same time, hip-hop also stakes a claim for an African tradition of digital representation, making this high tech arena a familiar space for their own expression. Rap is not Latifah's only influence however; she is best known for her fusion of the hip-hop sound with other, less digitally-identified musical forms. Her inclusion of reggae, in particular, signifies this hybrid identity.

While rap was emerging from the urban identities of the American disco scene, reggae invaded from the Rastafarian movement of Jamaica. Reggae has also made heavy use of technology in its recordings, but, like the electro-psychaedelic side of the hippie movement, restricts these sounds to flowing, continuous "vibes," using echo, reverb and slow multitrack fusions rather than the abrupt discrete splices of hip-hop. The sounds always have a "natural" feel to them, playing on the association of Africa with a physical dynamic. Reggae is analog representation par excellence, although it claims to be about the Real, not representation. Its lyrics speak of a unified natural African essence, redemption in nature and tradition, and Jah's "vibration positive."

Latifah's fusion of reggae with hip-hop accompanies several hybridizations in her work. She is ostensibly Afrocentric in her identity, wearing all black uniforms or West African prints and jewelery, showing footage from South Africa in her videos, and adopting several of the Rastafarian phrases about an essential African unity. At the same time she displays a mastery of urban American themes and techniques, splicing photos of Sojourner Truth and Angela Davis into the African-centered videos, rapping on homelessness and urban poverty in the US, and cutting the heavy reggae dub with digital breaks from mass media, scratch rhythms from her D.J., and other elements of hip-hop's techno-expertise.

Princess of the Posse missy she a cool one
she rhyme American she rap Jamaican
Princess of the Posse missy she a cool girl
she rhyme Brooklyn Dub Bronx U-S save the world*

While the analog/digital split of organicism is strategically manipulated in Latifah's work, her identity as "Queen" is similarly applied to undermine the recursive/nonrecursive split of humanism. Although she makes use of humanist phrases

*I'm not to sure if I have that last line right. As Latifah says earlier in the song, "you try to dissect my rhymes to see if there's a pattern/I bounced it all around you like rings around Saturn."

such as "self-determination," she also lays a strong claim to an African heritage of indigenous hierarchy. In her music this hierarchy didn't die in colonialism, nor does it surrender to the humanist democracy of neocolonialism. Transforming the ubiquitous Master of Ceremonies initials (eg M.C. Hammer) to Microphone Commando, Latifah plays a dangerous game of mixing militant revolution with the celebratory hedonism of the dance floor -- in her hands, an unbeatable combination. Similarly, she also showed herself to be a powerful competitor in the common one-upmanship of rap, but broke this convention by emphasizing collaborations and sharing space on her own videos with other female rappers.

Latifah is also well known for her stance on gender relations. Her album "All Hail the Queen" came out just when 2 Live Crew's obscenity arrests made gender-rap relations a national issue, and her "womanist" stance in her lyrics, which promotes an indigenous African "sisterhood" while distancing itself from white mainstream feminism, was upheld as a radical answer by writers from several political positions. For Michelle Wallace, who identifies herself as a "black feminist" rather than a womanist, Latifah was a perfect answer to groups like Oaktown 3.5.7., which Wallace saw as "the worst-case scenario: their skimpy, skintight leopard costumes... suggest an exotic animalistic sexuality." For *Essence* magazine's African-American fashions, Queen Latifah's use of traditional African fabrics was "Sensuous. Primeval. Animal skin is the original cloth. Conveying power and prestige, raw emotion and daring acts...." For *Rolling Stone,* Latifah signified "the year women rapped back," keeping this commercially important music within acceptable ideological limits of their readers.

Latifah's own view is dynamic, depending on whether she is speaking at Harvard University (where she recently appeared on a panel for "women, the arts, and politics"), or rapping with her friends in 2 Live Crew. The title of her hit single, "Ladies First," emphasizes this hybrid of women's power with a love for tradition, a "King and Queen

Creation." As with the case of all her work, she makes the synthesis of opposites a place where both harmonies and dissonance rock.

Unlike Latifah I have no artistic surface in which to inscribe my own dance between order and chance; the best I can do is a nerdy rendition in cybernetics. In the next chapter we will examine some of my technical work in attempting to derive an information science for the stable postmoden era, and in the last chapter, apply this methodology to an area of cultural analysis.

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Chapter 4: Towards a Cybernetics of Chaos

4.1 Introduction

In the last three chapters, we have looked at chaos/order distinctions for various cultural locations in terms of two attributes: recursive versus non-recursive information flow and analog versus digital representation. In this chapter we will examine some rigorous formulations of these attributes, with an eye towards applying this mathematical analysis to empirical studies of culture.

The mathematical analysis of human activity is notorious for its implications of domination and totalitarian control; my interest in using mathematical modeling as an oppositional practice is informed by three different concerns. An obvious one is the notion of application. The I.Q. test for example, originally invented to aid in education for the developmentally disabled, quickly became a tool for scientific racism (Gould 1981; see chapter 6 in his text for a critique of the global reconstruction mathematics in I.Q. models). A second concern is in historical contextualization. Understanding how I.Q. testing became intricately interwoven with the construction of a certain technosocial politics -- the ways in which racism became inscribed in testing technologies -- reveals the limitations of the "application" analysis, and shows that scientific bodies of knowledge are never simply neutral tools which can be arbitrarily applied to good or bad uses. The third concern is in the illusion of technological determinism. While scientific methods and objects are not neutral, neither are they inherently endowed with some eternal political or moral property. Their social meanings emerge from an interaction between internal practitioners and external context (an interaction which disrupts the internal/external division). Attempting to develop an effective scientific practice that is also responsible to social issues requires a strategic approach, an awareness that the cul-

tural meanings embedded in objects of science are constantly in flux -- even if it is flux itself that is the object.

In the first part of this chapter (sections 4.2 - 4.4), we will explore the notion that mathematical chaos can be understood in terms of certain types of recursive information flow. A consequence of this analysis will be a critique of Bak's harmony approach to mathematical chaos ("self-organized criticality"), which is analogous to my critique of the harmony approach in the social theories of stable postmodernism. The second part of this chapter (section 4.5) will examine the use of chaos theory in empirical studies, review their approach of global reconstruction, and offer an alternative approach to chaos theory based on the polysemic attributes of deconstructive methods from the humanities. In the third and last part of this chapter (sections 4.5 - 4.12), we will use this deconstructive dynamics in a model of analog-digital differences, and test this model with some empirical data from bioacoustics. Having covered this brief (and inadequate) attempt to give a rigorous foundation for the cybernetics of chaos, and having used the previous three chapters to outline the social and historical context/content of both cybernetics and chaos theory, the last chapter will proceed to apply this methodology in a specific example of cultural analysis.

4.2 Recursion and Computational Power

Although recursion is a common theme throughout the information sciences, there is no universal formulation into which all types of recursion can be translated, nor is there even a uniform definition. A semantic linguist might speak of self-referential sentences*, a control engineer may have an input signal which is a function of the output signal, a set theorist may be concerned with a set which includes itself as one of its elements, etc.. When I have approached chaos theorists with the idea that we can talk about

*This sentence, for example, talks about itself.

chaos as the outcome of recursion, it is no surprise that they respond with unenthusiastic confusion. What, exactly, do I mean by recursion? How do I know that there is some specific kind of "recursiveness" that leads to chaos? How do I know that there might not be some kinds of chaos that do not have this recursion, or cases of this recursion that do not result in chaos? And even if I can answer those questions, why should such answers be interesting or useful?

We will start this section by reviewing some elements from the most complete system for defining recursion in digital representations, the "Chomsky hierarchy" of computational power, and the recent mathematical research which uses this as the basis for analyzing chaos. Next, we will switch to recursion in analog representations through the control theory formulations for feedback. Finally, we will compare chaos in terms of analog feedback loops with chaos as defined by computational recursion. Both the analog and digital formulations here will be presented through the subjectivist or interactionist approach of holism advocates (Keller 1984, Harding 1987). I once met Evelyn Fox Keller, and confessed that although, as a loyal postmodern cultural theorist, I refuse to grant any inherent superiority to the holistic approach, I find myself unable to function without holism as a scientist. She responded with a broad and annoying grin.

Theoretical computation is based on the properties of sets of symbol strings. It is primarily concerned with various measures of computing power, either in terms of the ability to produce a certain set of strings, or of the ability to recognize a certain set of strings. For example, a machine that produced only true arithmetic expressions would, given "1+1=" as a starting string, finish it with 1+1=2. A machine that recognized only true arithmetic expressions would never accept 1+1=3. As to whether machines which implement these systems could be said to actually know or understand arithmetic, one enters the realm of philosophy.

There is a reciprocal relation of computing power between these two systems; here we will only consider symbol string recognizers. We will look at three of these abstract "machines" -- the Finite State Automaton, the Push-Down Automaton, and the Turing Machine -- and examine the differences in their computational power in relation to the differences in their recursive capabilities*. Figure Figure 4.1 illustrates the difference between a recursive system and a non-recursive system. The non-recursive system, such as a typewriter, does not have any behavior (output or change of internal state) that depends on its past; it only responds to its present input. In the recursive system, present behavior does depend on past behavior. It is the capabilities of this access to knowledge of its past, or memory, that defines the recursive capabilities of the machine. Of course the use of time here ("past") is only to make the abstraction more understandable. One could (at the risk of offending strict Kantians) speak of spatial memory instead of temporal memory for example, or use a symbolic system that would make no reference to any physical dimension.

The Finite State Automaton (FSA) is illustrated in figure 4.2. In 4.2a the input is diagrammed as a tape with symbols. The machine has a set of internal states and a set of transition rules which determine which state it will change to in response to the current input and the current state. If the machine is in one of the accepting states when it gets to the end of the symbol string, it has "recognized" that string. In figure 4.2b an example of an FSA is given in state diagram form. The starting state is marked by a ">" pointer. The accepting state has a double circle (in this case it is also the starting state). The letter over each arrow indicates the input symbol which will trigger the transition indicated by the arrow. This particular FSA, operating on strings of "a" and "b," will only recognize

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*The term "recursion" is used in technical definitions in computational theory, but these are similar to my use in this text. For example, the phrase "primitive recursion" distinguishes a less powerful type of recursion than "general recursion," which refers to the set of all computable functions.

Figure 4.1: General recursive loop in computational systems

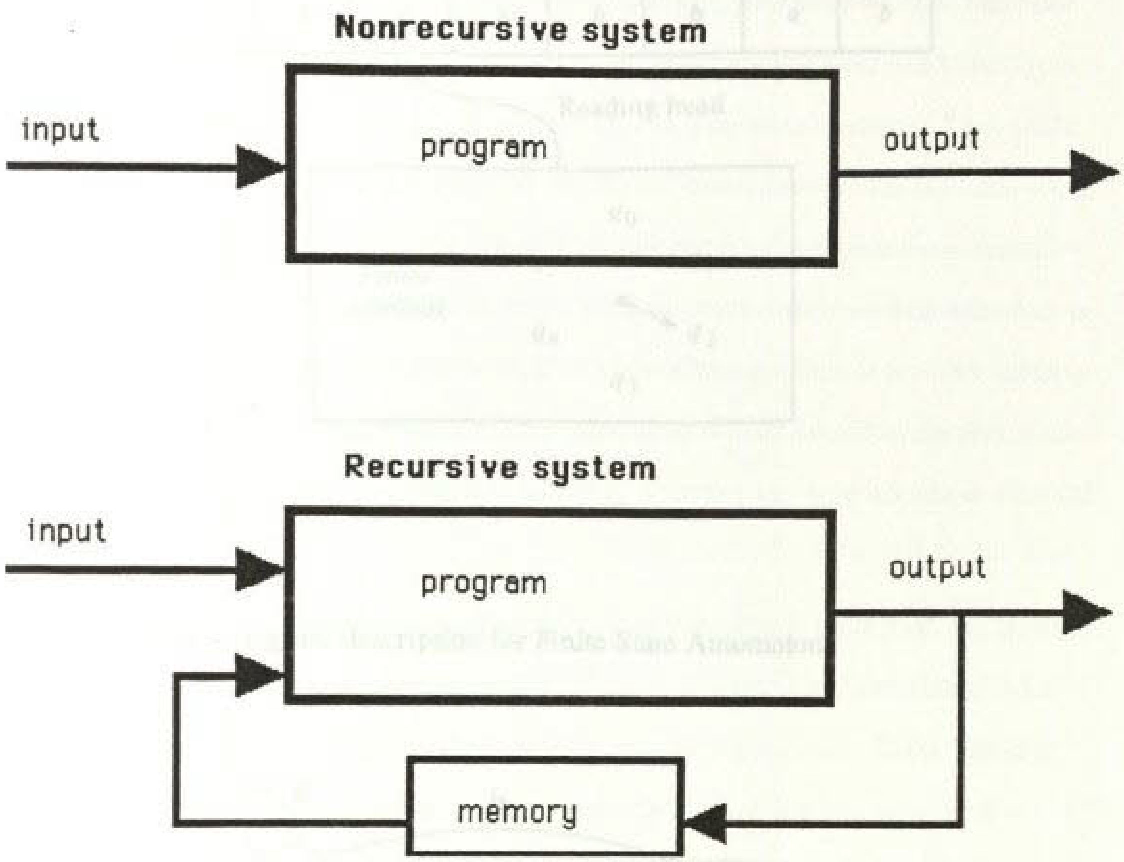
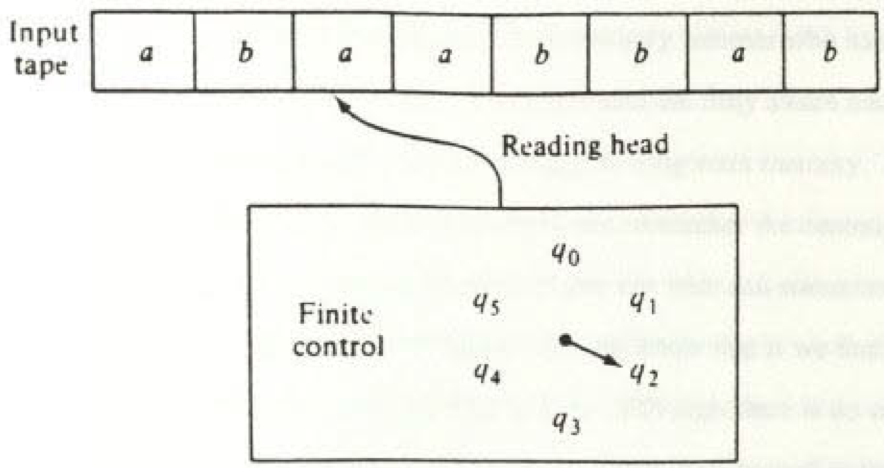
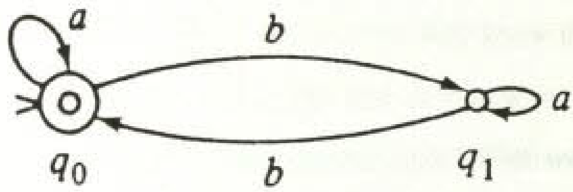


Figure 4.2: Finite State Automaton

a) Abstract machine description for Finite State Automaton



b) State diagram description for Finite State Automaton



From Lewis and Papadimitriou (1981).

(accept) strings with an even number of b's. It will stay in the accepting state, q_0, until it reads a "b," at which time it will change to state q_1, and remain there until it gets another b.

What would it be like to *be* an FSA?* Since the FSA has no memory storage, the experience would be somewhat analogous to neurosurgery patients who have had bilateral hippocampal lesions (Milner 1966). These patients are fully aware and intelligent, but have lost the capacity to transfer any knowledge to long-term memory. They could enjoy reading a magazine, for example, but would not remember the contents afterwards. An FSA has only an *implicit* memory, because its present state can sometimes reveal something about its past. In the FSA of figure 4.2b, we know that if we find ourselves in state q_1, we have encountered an odd number of b's -- although there is no other information about the past. The hippocampal surgery patient who finds herself at the end of the magazine can deduce that she has read its contents, although she does not know what the articles were about.

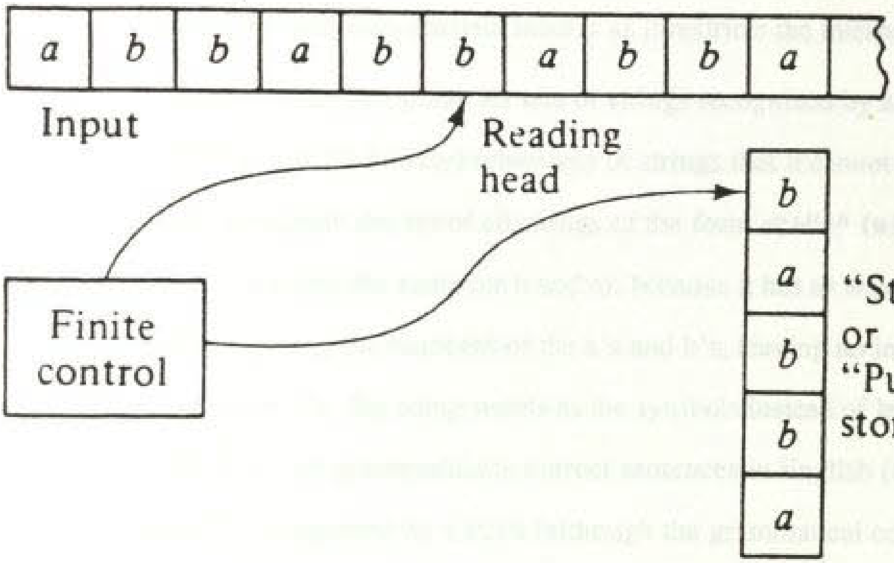
This implicit memory is even weaker in cases where there is more than one possible path to the current state. I am often reminded of the FSA when I try to convince reluctant graduate student employees that they should join our labor union. These students have knowledge of our current state -- for example, they know that we have health insurance -- but they do not seem to have any idea as to how we *got* there (i.e. they do not realize we had to go through a union-forming state before we were able to get to the health insurance state). "Learning from history" implies a recursive sequence -- the cyclic generation of new behavior based on the outcome of old behavior -- which is curtailed, for both automata and people, in the absence of explicit memory.

*This subjectivist approach should not be misinterpreted to imply that physical implementations of FSA machines have any kind of awareness; nor am I advocating the use of an FSA to model human behavior. It is not an effort to mechanize humans, but rather an attempt to humanize our understanding of mechanism.

There are many sets of strings (in fact, an infinite number) which cannot be produced by a FSA. For example, a machine which accepts the set of all palindromic strings -- strings in which the first half is the mirror image of the second (such as "aaabbaaa") cannot be an FSA, because it must memorize the first half to check it with the second. The least powerful machine capable of this memory storage is the Push-Down Automaton (PDA), illustrated in figure 4.3. The memory of the PDA is an external, explicit "stack" which is limited by its retrieval mechanism. The transition rules for each state tell the PDA whether to add to memory or recall from memory, and can use both memory and input symbols to determine the next state it will change to. This memory works like the spring-loaded tray stack often used in cafeterias; we push a symbol onto the stack to store it, or pop a symbol off the top to remember. The limitation of the push-down stack is that once a symbol is read from memory it is gone, and so retrieving a symbol buried down in the stack means losing all the memory that preceded it. Despite this limitation, a PDA has a much more powerful ability to perform recursive behaviors than the FSA.

As a human analogy, I am reminded of archaeologists. They can dig through layers of the earth to retrieve knowledge, but once it is dug up that layer is lost. Another analogy could be made to wine tasters. They destroy (consume) the information in the act of retrieving it, but will continue to store more as the next harvest arrives. Since they typically take the older wines first, the operation actually resembles a "FILO" ("First-In-Last-Out") stack rather than a push-down stack, but the computational power is similar. If I was pushed to make a political analogy, I might point out that the FSA could correspond to people who never read books, and the PDA would then be analogous to those who burn books after reading them -- the moral being that abstract cybernetic analogies can always backfire on us.

Figure 4.3: Push-Down Automaton



From Lewis and Papadimitriou (1981).

It is important to understand that the improved recursive abilities of the PDA does not mean that the PDA must repeat its past behavior more than the FSA does. On the contrary, nothing is more repetitive than an FSA bouncing back and forth between a few states. The PDA has a much greater flexibility. While limited, the explicit memory potentially allows it to recall every state that it passed through. Given the same state with the same input, a PDA can act differently due to its memory; it can recall that it has been there before and do something different the next time around. Greater recursive ability does not necessarily imply *larger* memory storage; it means an improved ability to *interact* with memory. Size only matters insofar as it restricts the interaction.

Although the PDA can recognize all sets of strings recognized by a FSA, as well as many others, there are still (infinitely) many sets of strings that it cannot recognize. For example, it cannot recognize the set of all strings of the form $a^N b^N c^N$ (where we have N repetitions of a, followed by the same for b and c), because it has to wipe out its memory in the process of comparing the numbers of the a's and b's, leaving no information for checking the number of c's. By using words as the symbols instead of letters, we can also show that the set of all grammatically correct sentences in English (and other natural languages) cannot be recognized by a PDA (although the grammatical constructions that defeat the PDA are quite rare; see Savitch (1989) for a recent review).

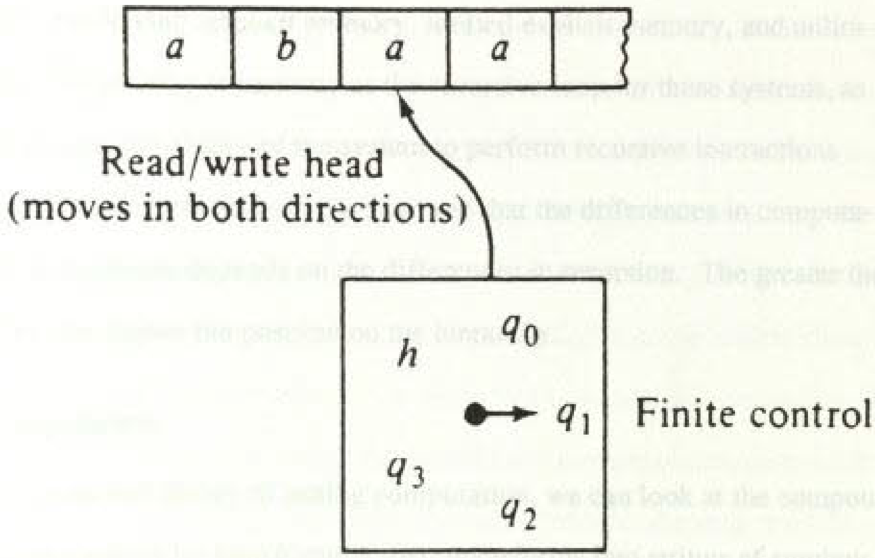
There are a wide variety of systems which have a higher computational power than the PDA. One of the most important distinctions for sets of strings is the set of "primitive recursive" functions, which is as close as we can get to the complete set of all computable functions without actually reaching that limit. Of particular interest is the fact that the field of primitive recursive functions was founded by a woman, Rózsa Péter (Morris and Harkleroad, 1990). Like Kovaleskaia, Péter was both a strong feminist as well as a powerful mathematician, although her feminist position was more one of holistic essentialism, with women as the natural bearers of decentralization in science. Her

work provides another example of a relationship which has been hinted at earlier in this text, and will arise again in the next chapter: cultural ideas about recursion in sex/gender identity have often accompanied technical formulations of recursion. We have already examined, in chapter 1, the role of sexual orientation in work leading to the most powerful automaton, one which covers the set of all computable functions: the Turing Machine.

The Turing Machine (TM) is illustrated in figure 4.4. It is simply a PDA without the memory limitation. The storage tape is an infinite strip, not a stack, and the read/write head can scan anywhere on the tape. But this unlimited access to memory -- the ability to read and write unlimited numbers of symbols, without losing what is read -- allows the TM to implement anything that can be expressed as a formal system (sometimes referred to as the RE set, for "recursively ennumerable"). Since the primitive recursive functions are defined by the set of all functions with predictably terminating programs (that is, all functions for which we can prove that the program for generating the function will eventually stop), the unlimited memory of the TM is the one feature that allows it to take the next step up the Chomsky hierarchy, to the final limit of all computable functions. Anything that will ever be possible to compute, could be computed on this system. Alan Turing's thesis on the human significance of this system -- that our own symbol strings are also encompassed by this formalism -- is at the center of philosophic debates on machine intelligence.

To continue my subjective analogy, if the FSA is a society with no books, and the PDA is a society in which books are burned after they are read, then the TM would be a society in which books have a potentially infinite existence. These would be distinguished from the libraries of primitive recursive functions, in which all knowledge is guaranteed to require books with only a finite lifespan. Of course, a program which really did take an infinite amount of memory could not operate, since we would have to wait an infinite time for the answer, but allowing for programs in which we can't be

Figure 4.4: Turing Machine



From Lewis and Papadimitriou (1981).

certain of termination lets us include some terminating programs that would have been excluded by primitive recursion. It also allows Gödel's flaw to emerge: we can prove that there is no method for completely separating the programs with a finite running time from those with an infinite running time (thus there are true propositions ("this program will terminate") in this system whose truth cannot be determined by the system).

These three machines, FSA, PDA, and TM, illustrate the ascent up the Chomsky hierarchy. They differ in having implicit memory, limited explicit memory, and unlimited explicit memory. By looking at memory as the recursive loop for these systems, as the element which governs the ability of the system to perform recursive interactions between its present input and past behavior, we can see that the differences in computational power for these machines depends on the differences in recursion. The greater the recursive capabilities, the higher the position on the hierarchy.

4.3 Chaos and Computation

Although there is no real theory of analog computation, we can look at the computational power of analog systems by transforming their waveforms into strings of symbols, and finding the lowest machine in the Chomsky hierarchy that is capable of recognizing that set of symbol strings. This is precisely the method used by James Crutchfield (one of the UCSC Chaos Cabal) in his recent analysis of the simplest know chaotic system, the logistic map. Crutchfield is one of the few chaos researchers who has promoted the idea of recursion as fundamental to chaos. This is beautifully visualized in his *Video Feedback* project (available from Aerial Press), where he used a video camera pointed at its own monitor to produce dynamic illustrations of point attractors, limit cycles, and chaotic attractors. Jim strikes me as a heck of a nice guy, but I don't know him well enough to see how the aspects of personal identity I have discussed previously in this text -- race, sexual orientation, etc. -- would be illuminated by his appreciation for recursion,

and it's possible that they wouldn't. Within the Cabal he was the most extreme in his dual membership as both a hippy and a hacker, which may be noteworthy enough in itself: Bass (1985, pp 137-139) describes Jim's social transfers between psychedelic communes and the silicon valley, which happened during the time Jim developed the Cabal's electronic system for data transfer between their analog and digital computers.

Crutchfield's more recent work takes the waveform produced by the logistic equation $X_{(n+1)}=RX_n(1-X_n)$, converts it into a data stream, and creates a probability matrix for the various symbol strings. This information is converted into a set of states and transition rules, and finally into the minimal machine (usually an FSA) capable of implementing this recognition task. By comparing the minimal machines at various parameter settings of the equation (including the addition of random noise), the computational characteristics of these waveforms can be compared. In contrast to Kolmogorov's algorithmic complexity, in which the most random waveforms were the most complex, measuring the complexity of the FSA provides a measure of the waveform's computational complexity. Here data sets that were simply periodic, and data sets that consisted of purely random noise, could both be recognized by very simple FSAs. But as the equation began to approach a chaotic output, the complexity of the FSA rapidly grows. When we reach a chaotic output, the FSA requires an infinite number of states -- in other words, a FSA does not have enough computational power to recognize even the simplest chaotic output. But this does not require a TM; a PDA is fully capable of recognizing the data stream produced by the logistic equation's chaos.

How do these results relate to our understanding of the differences in recursion between the FSA and the PDA? For a purely periodic waveform, memory is trivial. In a constant squarewave, for example, the FSA merely needs to go back-and-forth between two states. When in the high level state, go low, and vice-versa. More levels just require more states. For a purely random waveform, the probabilistic characterization of the

states also makes the FSA memory trivial. There is a finite probability for any string sequence. In subjective terms, we could think about neurotic conditions in which someone repeats the same phrase over and over, versus psychotic conditions where someone is talking "word salad," a jumble of nonsense. In both cases, their mental relation to memory is pathologically simplified: they either slavishly follow memory, or they ignore it all together. As a social analogy, we might imagine a centralist, totalitarian society, where everyone obediently follows the rules over and over, versus a lassez-faire, individualist anarchy, in which everyone follows their whims. Complex information processing requires a dynamic interaction with memory; i.e. a non-trivial recursive loop.

When I read Crutchfield's work, I was excited but worried. He had not demonstrated an analog system with a computational power equivalent to a TM, and it seemed possible that his work might lead to a proof that no such analog system existed -- a devastating blow for my position on the epistemological equivalence of analog and digital representation. Fortunately, at the same time that Crutchfield demonstrated that the logistic equation required a PDA, Smale and others had published a proof demonstrating that TM computability was required for certain chaotic sets.* They took a different approach, modifying the original TM design to operate over the real numbers, as opposed to discrete mathematics. This allows their machine to implement chaotic equations directly. Like the original TM, there are undecidability problems for these analog computing systems. Universal analog machines can no more escape Gödel's trap than their digital equivalents can.

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*Smale told me that my interpretation of his work as demonstrating universality in analog computation was correct, although he said he was not convinced that only chaotic systems were computation-universal. He also said that recursion in his analog TM, which occurred when branch nodes looped back to computation nodes, always accompanied chaos, but not vice-versa (which I would expect), and that my interpretation of the role of recursion was backwards -- from his perspective, chaos generated recursion, not the other way around.

4.4 Chaos and Control: recursion in analog feedback

Crutchfield and Smale's work is quite new, and while it may someday lead to a thriving theory of analog computation, it is as yet only bits and pieces. Recursion in analog systems has had a long history, however, in the form of feedback theory. In this section we will look at recursion in this control theory formulation, examine a chaotic system in these terms, and compare this to the computational recursion previously discussed. Again, we want to address two questions. Is it possible to have chaos without recursion? And given the fact that many systems are both recursive and non-chaotic, what is unique about the recursion taking place in chaos?

The conjecture presented here, which we will later see as incorrect, simply states that coupling between negative and positive feedback is a necessary condition for deterministic chaos. Positive or "deviation amplifying" feedback is the familiar "vicious circle" encountered in economic inflation, poison oak irritation, and other self-exciting systems. Negative or "error correcting" feedback suppresses noise and keeps things in a steady state, as in a thermostat. In terms of dynamical systems theory (Abraham and Shaw 1982), positive feedback would be associated with spreading in phase space, and negative feedback with folding in phase space. An example of a negative feedback loop would be a point attractor, and a point repellor would be an example of a positive feedback loop. The phase space combination of local spreading and global folding is a common definition for chaos; this simply translates the phase space definition into a control theory formulation.

The use of feedback in simple water storage systems, where a float rises with the water and shuts off the supply when the level gets too high, is quite ancient. One of the first uses of feedback in the industrial revolution was the condensing pumps of 18th century British coal mines. According to the *Encyclopedia Britanica* (11th ed, Vol 25, p820), a worker who tired of opening the pump valve himself attached a rope between

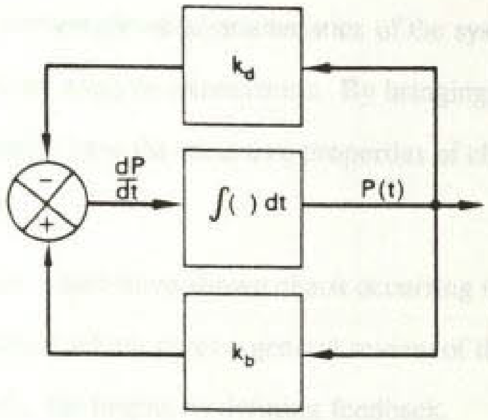
the steam piston and the pump valve, so that the engine and pump became a self-regulating system. I am particularly fond of this story since it hints at the existance of a hidden science history of the working class. As in the case of other identities, such as women in science, it would be valuable to have an idea of the extent to which their contributions have been unacknowledged.

Following the pre-WWII work of Bode, Weiner and others, feedback changed from a device design to a mathematical construct. After WWII, this new mathematical community bifurcated along what would become both technical and social divides. While the cybernetics branch were interested in explicit representations of the feedback equations, the General Systems Theory (GST) branch wanted only general distinctions between positive and negative feedback, with the idea that very large systems (e.g. agro-economics) could be mapped out into a chain of positive and negative feedback components. These two types of control graphs are illustrated in figure 4.5. Note that the negative and positive symbols for the summation box in the cybernetic feedback loop, where the fedback output signal is combined with the reference or threshold signal, appear to be the counterparts to the symbols used to distinguish negative and positive feedback in the GST loops. This is not always true.

Although the two symbols do coincide for many of the simple feedback loops that were first investigated, it is possible to have negative summations in a feedback loop which is deviation-amplifying, which would make it "positive feedback" for the GST crowd. The reverse is also possible. But there was a strong ideological split between these two groups that hinged on maintaining this separation, and thus ignoring the contradiction. According to von Bertalanffy (see Davidson 1983, pg 204), GST would be the only systems science capable of maintaining a humanist focus, because it kept its analysis at a qualitative level, whereas cybernetics was trapped into a quantitative analysis that forced it to model with explicit equations. As a result of this ideological

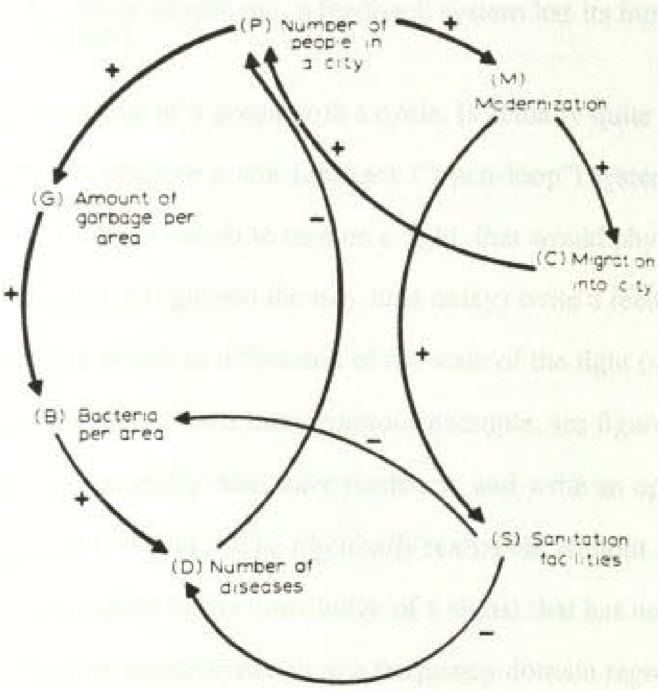
Figure 4.5: Comparison of cybernetic feedback graph and GST feedback graph

cybernetic feedback graph



Growth process, including birth and death rates.

GST feedback



A multi-loop model of urban ecology.

From Milsm (1968).

split, feedback theory suffered from a technical split between mathematical analysis and global feature characterization. One of the main advantages of chaos theory is that it has bridged this gap. We can discuss global characteristics of the system in quantitative terms, and relate these to local analytic expressions. By bringing feedback analysis back into the picture, I hope to show how the recursive properties of chaotic systems are fundamental to their operation.

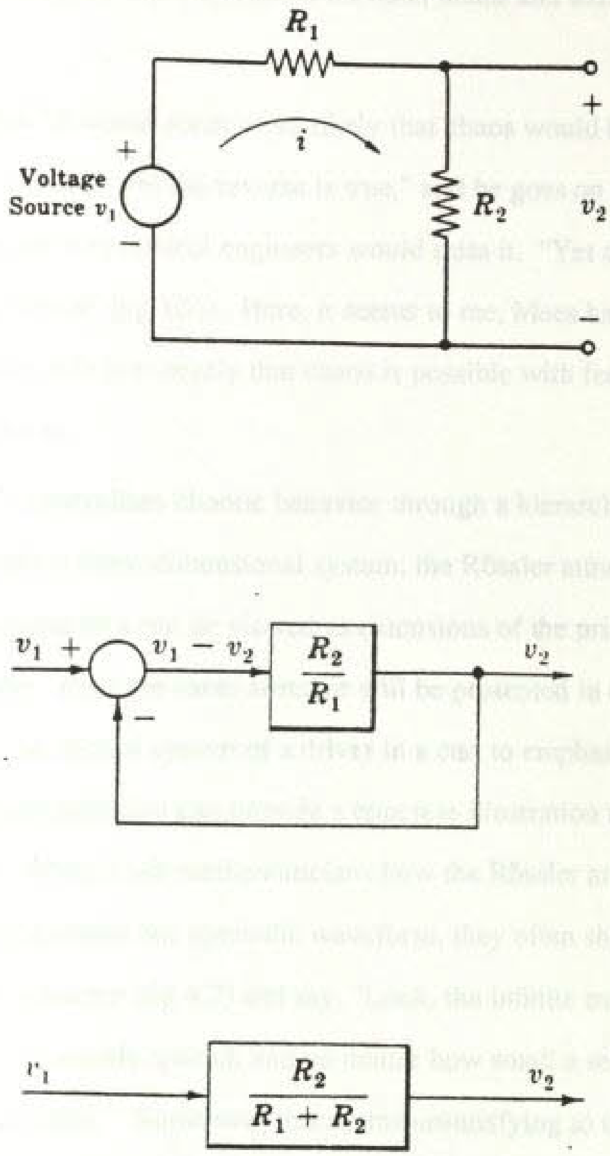
There are many studies which have shown chaos occurring in a feedback system. The only writing I am aware of which gives a general review of the feedback concept in chaos theory is Mees (1984). He begins by defining feedback.

> We think of a *system* as a causal connection between a set of time functions v called *inputs* and a set of functions y called *outputs*. the outputs of one system inputs to another, and we can represent the connections by a directed graph. A *feedback system* is then a set of interconnected systems for which the graph contains a cycle. More simply put, a feedback system has its inputs affected by its outputs (pg 101).

This definition, in terms of a graph with a cycle, is actually quite problematic. For example, it is possible to describe a non-feedback ("open-loop") system with a closed-loop graph. If I flip on a light switch to turn on a light, that would physically be an open loop. But I could (assuming I ignored the tiny time delay) write a feedback graph that describes the state of the switch as a function of the state of the light (sort of like the cock crowing to make the sun rise). For a more rigorous example, see figure 4.6. In addition, we can take a system which really does have feedback, and write an open loop control graph for it, even though it would not be *physically* realizable without a loop (the open loop description would require either knowledge of a signal that has not yet occurred, or elimination of time through transformation to a frequency domain representation). What is missing from Mees' definition of feedback is the notion of memory. In any physically extant feedback system, there must be a time separation between the original input's transformation to an output signal and this output's return back to the input node.* In

*In addition to time delay operations, there is another basic class of memory phenomena in feed-

Figure 4.6: Equivalence of open loop and closed loop descriptions.



From Distefano (1967).

fact, the transition to chaos in feedback systems is often triggered by an increase in this delay -- a result which parallels the relation between chaos and memory in computational theory.

Mees notes that "it would seem more likely that chaos would have first come to notice in feedback systems, yet the reverse is true," and he goes on to give an excellent analysis of the reasons why control engineers would miss it. "Yet chaos is certainly possible in feedback systems" (pg 101). Here, it seems to me, Mees has inverted my thesis. From my perspective, it is not merely that chaos is possible with feedback, but that chaos is impossible without it.

Rössler (1983) generalizes chaotic behavior through a hierarchy of complexity. He begins with the simplest three-dimensional system, the Rössler attractor, and suggests that more complex dynamics can be viewed as extensions of the principles governing this low dimensional case. Here the same attractor will be presented in control theory terms. It is instantiated as the control system of a driver in a car, to emphasize the ways in which a feedback representation can provide a concrete illustration for information flow in a chaotic system. When I ask mathematicians how the Rössler attractor can give endless variation, a deterministic but aperiodic waveform, they often show me the phase space portrait of the attractor (fig 4.7) and say, "Look, the infinite trajectories packed into this finite space are not evenly spaced, and no matter how small a section you look at, there is still more variation." Somehow, this seems unsatisfying to me, as if infinite variation were explained by showing that it varies infinitely. What I really want to know is what it's like to *be* a chaotic attractor.

---

back loops called "hysteresis," in which a nonlinear control acts differently on the same input value depending on whether it's past trajectory came from above or below this value. It would be well worth the trouble to trace the parallel etymology with "hysteria" (greek for "memory of the womb"), a psychoanalytic framing of memory which has had profound implications for feminist theory.

Figure 4.7: Phase space portrait of the Rössler attractor

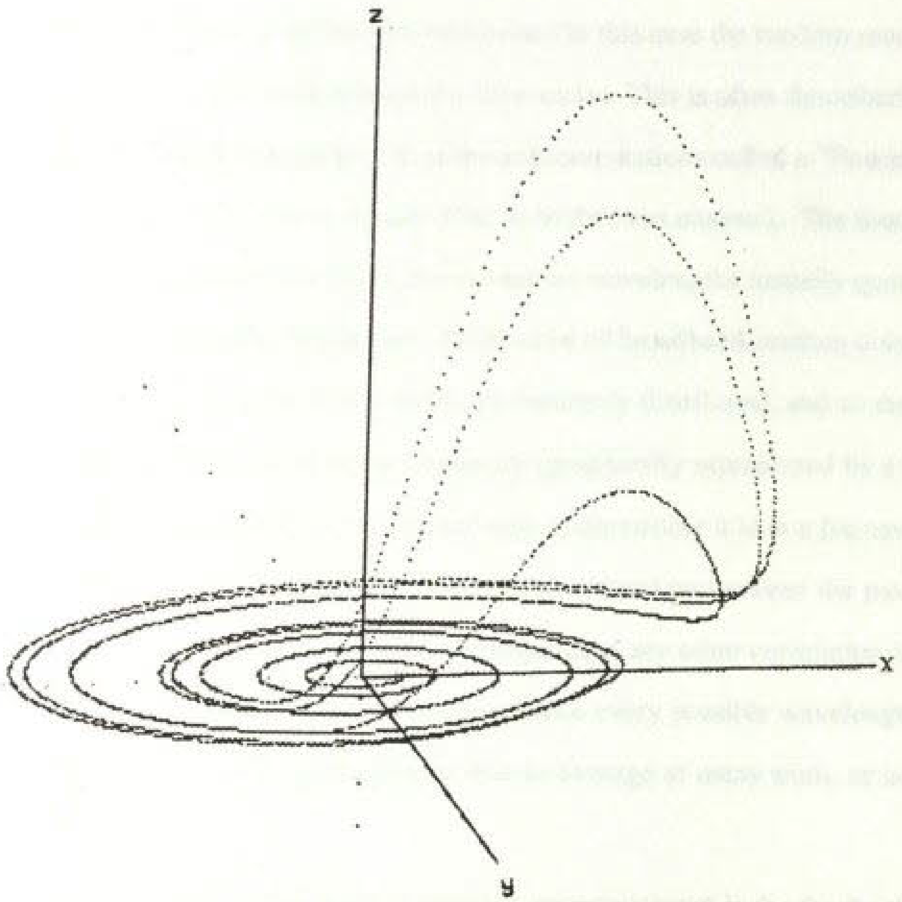
First 5,000 iterations of the Rössler attractor, with timestep .01 and Runge-Kutta integration.

$dy/dt = x + ay$

$dz/dt = b + z(x - c)$

$dx/dt = -y - z$

$a = b = 0.2, c = 5.7$

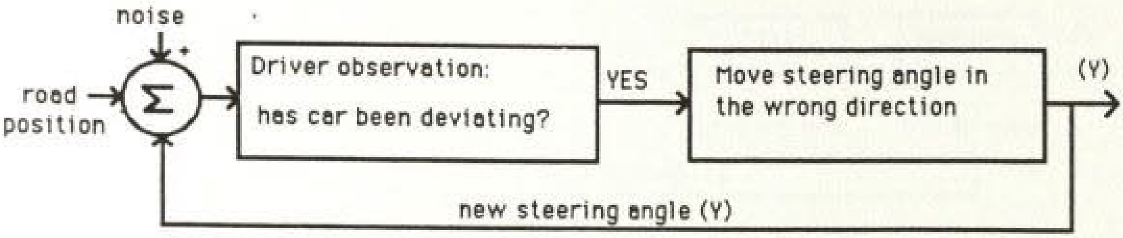


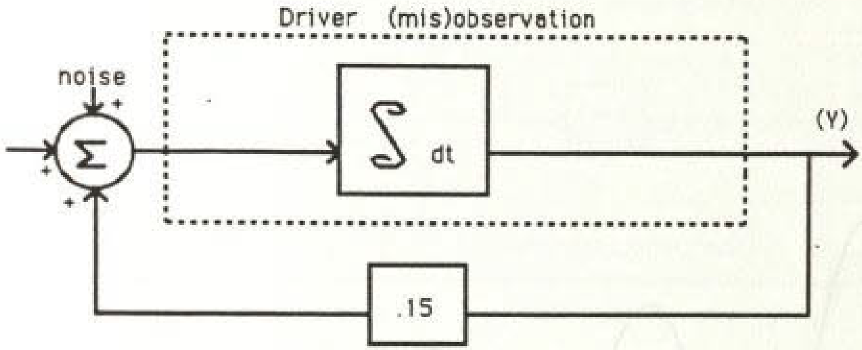
Simple feedback control models for car driving have been well explored (c.f. *Human Factors 19(4) 1977)*. Here I have a similar model with the addition of a "caution" threshold, and the presence of randomly distributed bumps on the road. The first equation of Rössler's attractor is represented in the feedback loop of figure 4.8. Here a reckless (e.g. drunk) driver is governed by a positive feedback loop. A bump in the road causes the driver to increase the steering angle - the driver steers in the direction of the bump. The deviations are amplified, and the car is quickly driven out of bounds. In figure 4.9 this equation is graphed as a time series. If we look at this as an aerial view of the car, we can see the path taken after hitting a bump.

In a positive feedback loop background noise (in this case the random road bumps) is amplified, and eventually it dominates the time series. This is often described in terms of the waveform's "power spectrum" (in some implementations called a "Fourier spectrum" after Joseph Fourier, whom we will look at in the next chapter). The fourier spectrum simply graphs the power of the signal at various wavelengths (usually quantified by the reciprocal of wavelength, frequency). In the case of broadband random noise, or "white noise," the wavelengths of the signal are randomly distributed, and so the power of the signal is about the same at every frequency (graphically represented by a flat horizontal line in the power spectrum). A related way of describing it is in a framework termed "auto-correlation." In white noise there is no correlation between the past and the present (that is, no one correlation length is stronger than any other correlation length). Of course, a real car would not get the chance to make every possible wavelength before it went out of bounds, but we could consider this an average of many trials, or an extraordinarily wide road.

The last two equations of Rössler's attractor are represented in the feedback loop of figure 4.10. The cautious driver is governed by a negative feedback loop. When a bump on the road (background noise) causes a deviation in road position X, the driver

Figure 4.8: Positive feedback loop in the Rössler attractor modeled as a reckless car driver.

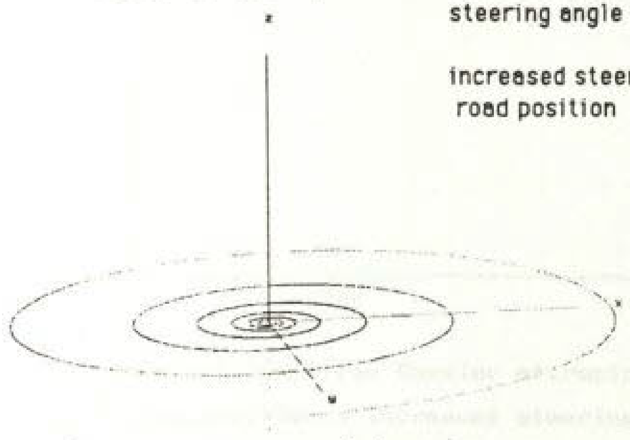




X = deviation from proper road position
Y = angle of steering wheel (measured clockwise from horizontal)

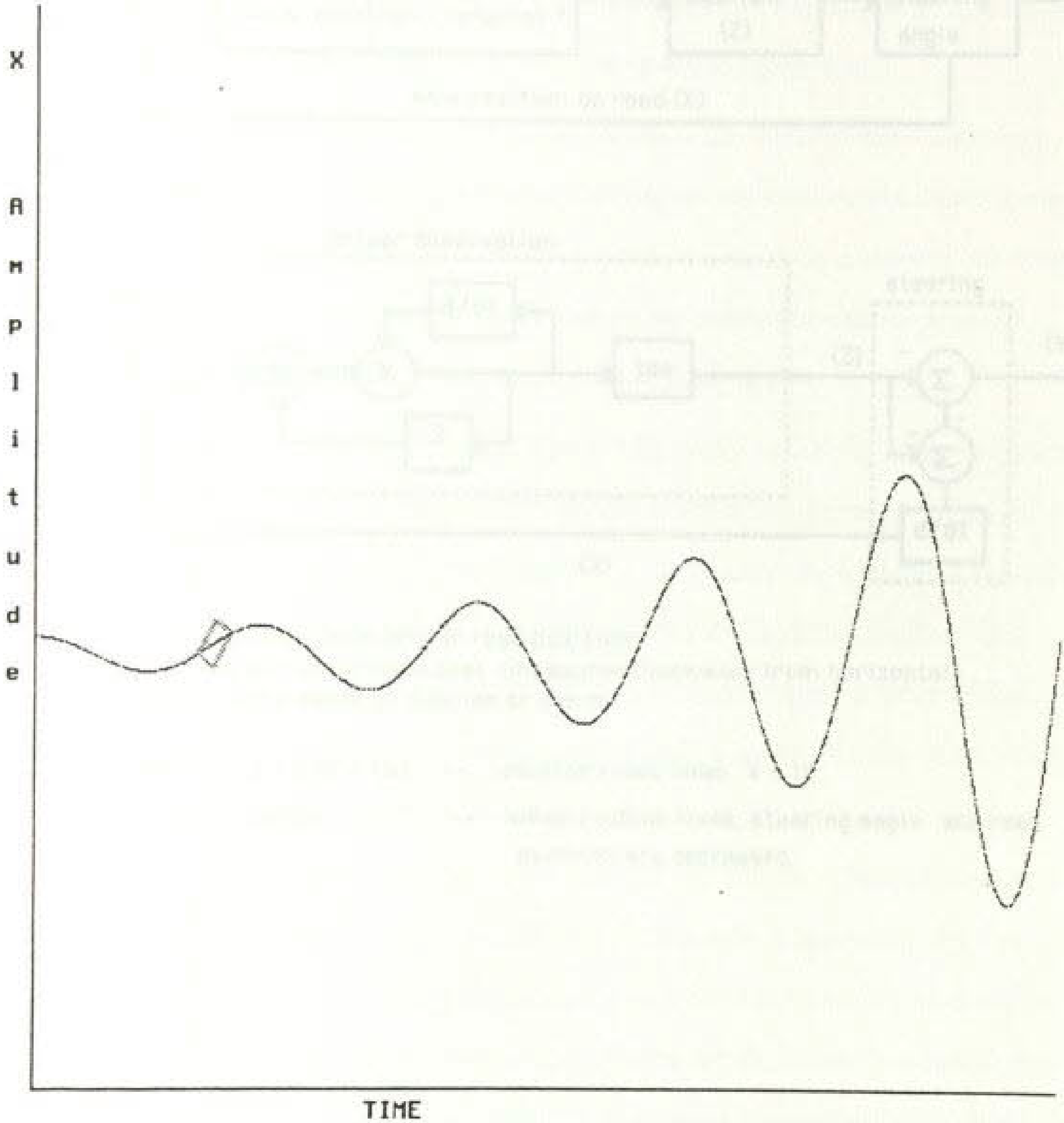
dY/dt = X + .15 * Y -- increased road position causes increased steering angle

increased steering angle causes increased road position



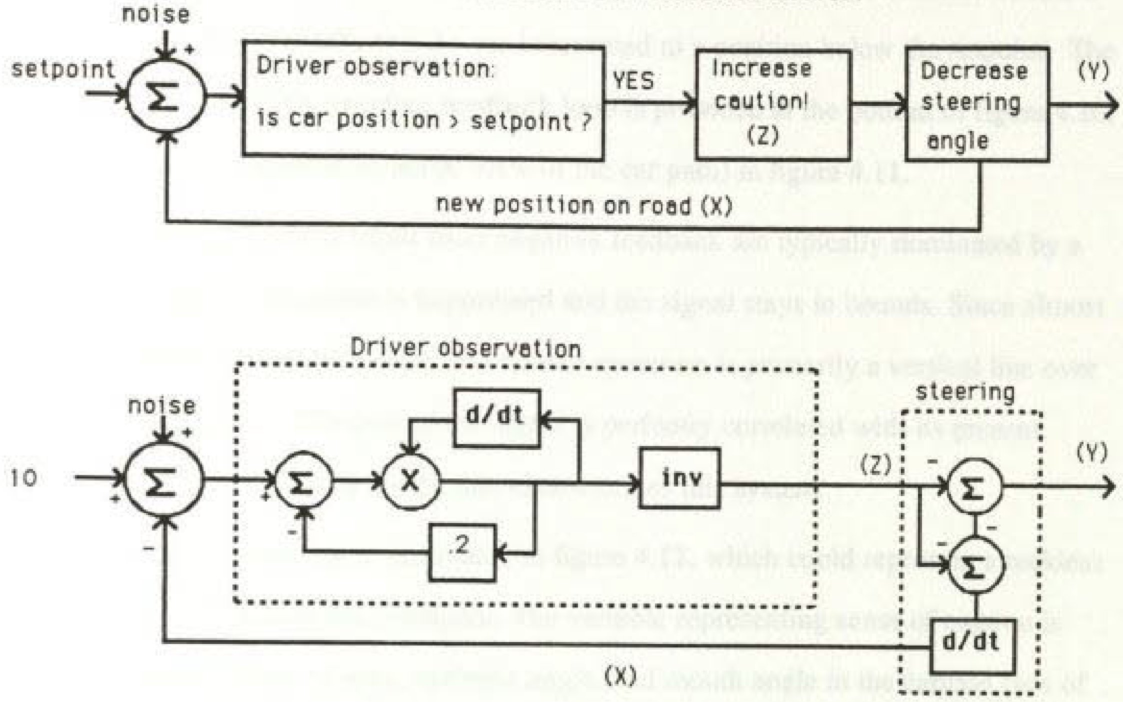
Phase space portrait

Figure 4.9: Automobile model time series for positive feedback loop



Positive feedback loop from Rossler attractor as automobile control. Road position X increases steering angle Y, and Y increases X

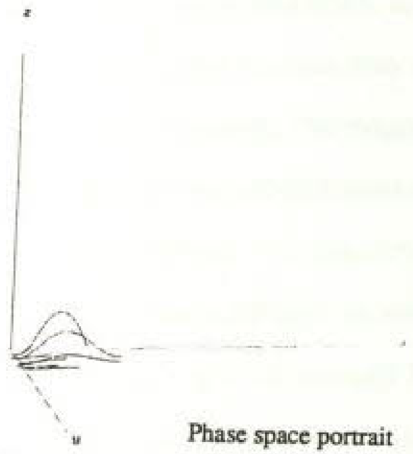
Figure 4.10: Negative feedback loop in the Rössler attractor modeled as a cautious car driver.



X = deviation from proper road position
Y = angle of steering wheel (measured clockwise from horizontal)
Z = driver's sense of caution or alarm.

dZ/dt = .2 + Z (X - 10) -- caution rises when X > 10

Z = -Y - dX/dt -- when caution rises, steering angle and road position are decreased.



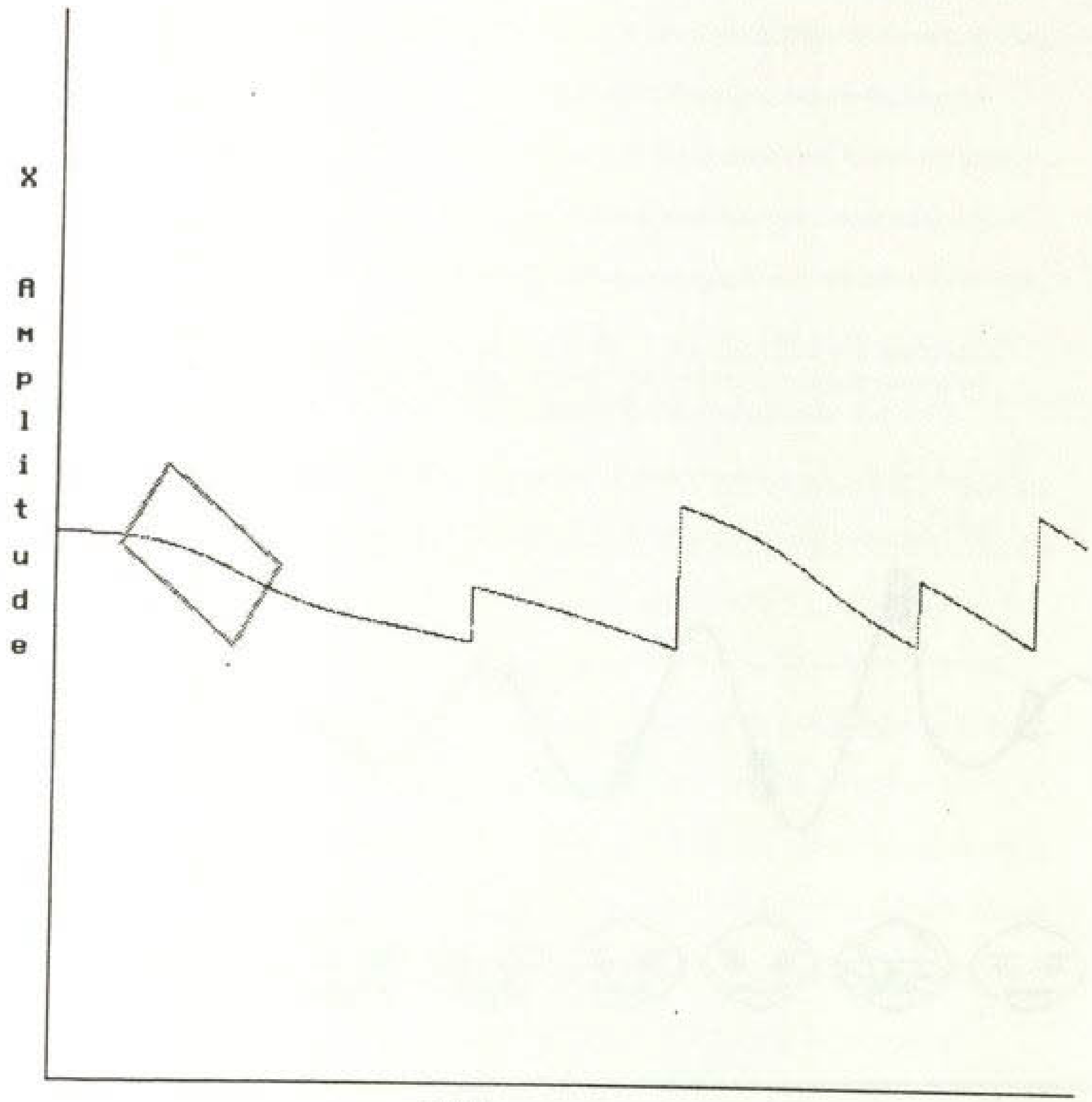
Phase space portrait

compares the new position to the reference or threshold value. If this threshold is exceeded, the driver's sense of caution Z is increased. This increase in caution causes a decrease in steering angle Y, and the car is returned to a position below the setpoint. The phase space graph of this negative feedback loop is provided at the bottom of figure 4.10, and its time series (again as an aerial view of the car path) in figure 4.11.

The time series which result from negative feedback are typically dominated by a periodic oscillation - the noise is suppressed and the signal stays in bounds. Since almost all of the signal is at one frequency, the fourier spectrum is primarily a vertical line over that single periodicity. The past of the signal is perfectly correlated with its present. There is only one correlation length that characterizes this system.

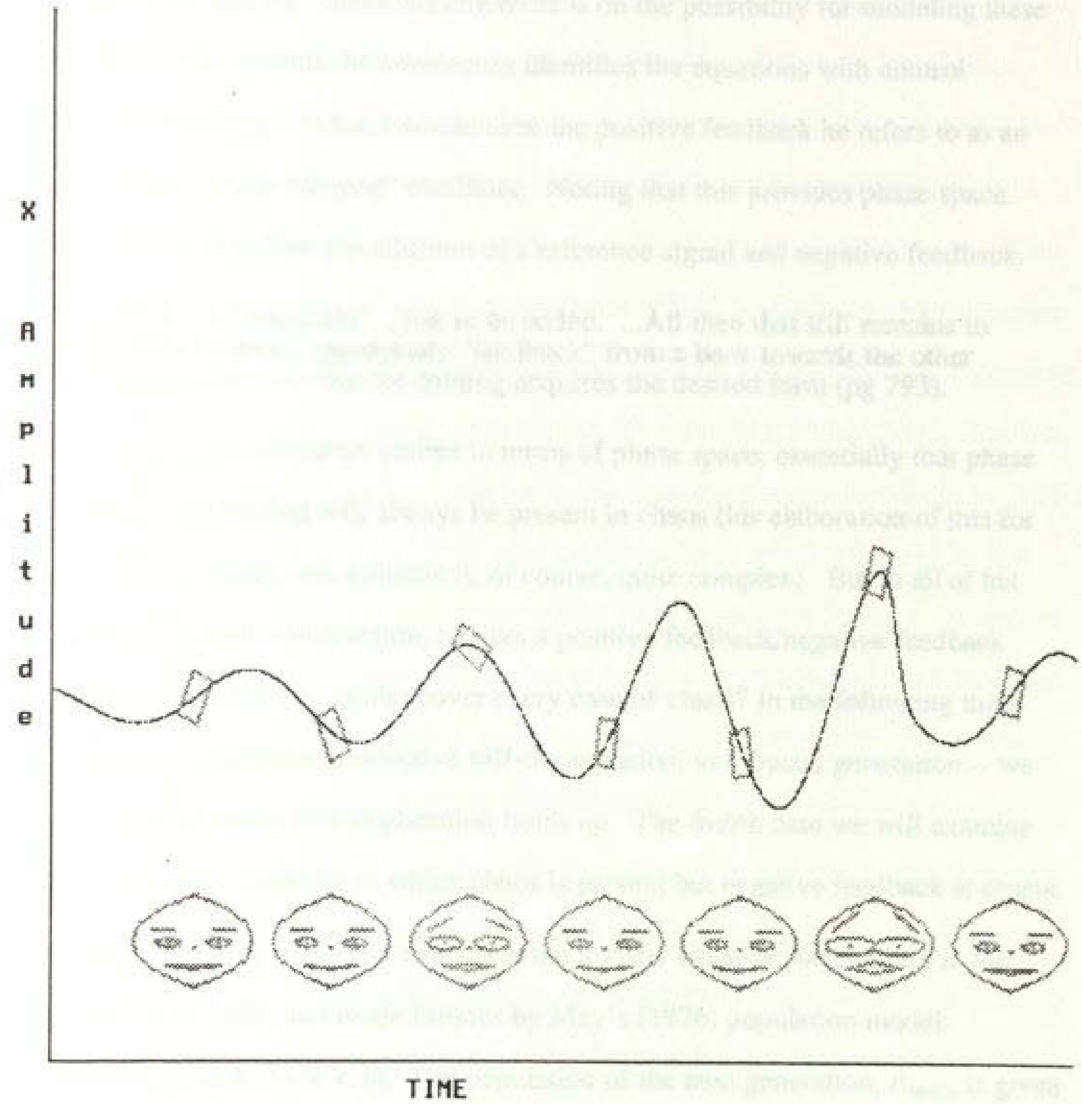
The complete attractor is assembled in figure 4.12, which could represent a reckless student driver with a cautious instructor. The variable representing sense of caution is graphed by the diameter of eyes, eyebrow angle, and mouth angle in the cartoon face of the driver. While the positive feedback causes deviations, the negative feedback loop brings the car back in bounds when the threshold is exceeded (as seen in the sixth face). It is important to note that the positive feedback continues to cause deviation even while the negative feedback is bringing the car back into bounds. For this reason, it never brings it back to the same spot it left, and so the variation is infinite. The road bumps need not exist in this model, since they would serve no purpose -- this system, like so many of us, is self-deviating. The diagonal power spectrum of chaos can be viewed as a compromise between the vertical spectrum of negative feedback and the horizontal spectrum of positive feedback. It is not completely orderly, nor is it completely disorderly. It has correlations at many different wavelengths, but there is a non-random overall pattern: the longer the wavelength, the stronger its power. Power tends to vary as the reciprocal of the frequency (F), and for this reason, the chaotic power spectrum is often referred to as "1/F noise".

Figure 4.11: Automobile model time series for negative feedback loop



Negative feedback loop from Rossler attractor as automobile control. Road bumps cause deviation, feedback corrects.

Figure 4.12: Automobile model time series for complete Rössler attractor



Rossler attractor as automobile driving system. X amplitude is road deviation, Y is steering angle, Z is driver's 'alarm.'

Rössler presents these features in terms of phase space for a variety of chaotic systems - the Hénon map, Van der Pol oscillator, and on up to higher dimensional attractors. In all of these cases, he notes that local phase space stretching is accompanied by global phase space folding. Since his emphasis is on the possibility for modeling these systems in electronic circuits, he sometimes identifies the equations with control engineering terminology. What I would term the positive feedback he refers to as an "unstable" or "negatively damped" oscillator. Noting that this provides phase space stretching, he then describes the addition of a reference signal and negative feedback.

> To this flow... a "threshold"... has to be added. ...All then that still remains to be done is to insert an appropriate "feedback" from z back towards the other variables to make sure that the folding acquires the desired form (pg 793).

Rössler only makes his universal claims in terms of phase space; essentially that phase space stretching and folding will always be present in chaos (his elaboration of this for increasingly higher dimension systems is, of course, quite complex). But in all of his examples detailing their construction, he uses a positive feedback/negative feedback 'recipe'. Does this feedback combo cover every case of chaos? In the following three cases -- a difference equation, collective self-organization, and fractal generation -- we will look at systems where this explanation holds up. The fourth case we will examine is, however, a counter-example in which chaos is present but negative feedback is absent.

The simplest example for this concept is the logistic equation, originating in the work of Verhulst in 1838, and made famous by May's (1976) population model: $P_{(n+1)}=P_n*R*(1-P_n)$ (with $0 < P < 1$). The population of the next generation, $P_{(n+1)}$, is given by the current population P_n multiplied by two factors: R, a rate of population increase -- positive feedback -- and $(1-P_n)$, a rate of population decrease which becomes stronger as the population gets large - a negative feedback loop.

The most complicated example of chaotic dynamics belong to the collective self-

organizing systems in which there are large numbers of autonomous units. In physics this has been generally approached through the concept of a "critical state," as in the case of phase transition. The ability of systems to maintain themselves in such states has been termed "self-organized criticality" by Per Bak and others, who have championed an intuitive and accessible approach to this study of global properties (Bak and Chen 1991). Consider, for example, a crystalline solid. Here the geometry is periodic, and perturbations are absorbed as negatively damped oscillations. If the solid is transformed into a liquid, then the geometry is that of white noise. Any structure that starts to form will be torn into pieces by smaller particles, and those pieces will be available to tear apart other structures - a positive feedback. In the transition between the phases a critical state exists in which these two processes combine; the result is 1/F noise (e.g. snowflakes). Bak has shown that both models and empirical data for a wide variety of physical systems -- sand piles, earthquakes, forest fires, etc. -- indicate a critical state in which 1/F noise results from a balance between noise-amplifying and noise-suppressing mechanisms. A similar combination of negative and positive feedback can be seen in the interaction of anabolic and catabolic processes in biological systems; Bak has also demonstrated 1/F noise in cellular automata models for the "game of life" and similar organic simulations.

Although fractals are usually seen as static structures, they are generated by a recursive process*, and in Barnsley's Iterated Function Systems and Mandelbrot's algorithms for generating fractals there are formulations of the contraction ratio which correspond to feedback. Consider a seed shape made of line segments and subsequent iterations which

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*In *The Science of Fractal Images* Dietmar Saupe discusses fractal algorithms, and notes that "in some cases the procedure can be formulated as a recursion" (pg 72) -- a statement which appears similar to Mees' suggestion that it is merely "possible" to have chaos in feedback systems. Actually Saupe is using "recursive" to refer specifically to a programming technique where a procedure or function calls itself. He notes, however, that in all cases, the "process is repeated with outputs used as new inputs until the desired resolution is achieved." In other words, recursion is always present in the sense of feedback, but how this loop in the dynamic information flow is reflected in the software structure is a matter of programming style.

replace each segment with contracted seeds of the same length as the segment. A seed shape with a huge number of tiny line segments will tend to be shape-preserving under self-replacement iterations; here deviations due to replacement are damped - the difference between a line segment and the seed shape is usually not important. Periodic structures stay periodic. For seed shapes made up of only a few large lines, the difference between a line segment and its replacement shape will be very important. Large deviations tend to be amplified in a quick positive feedback, sometimes explosively growing out of bounds in only a few iterations. Euclidian seeds dissolve into white noise. Fractal structures (i.e. those with a spectra tending toward a 1/F distribution) can be viewed as a balance between the negative feedback of small segment shape preservation and the positive feedback of large segment replacement deviation.

With this consistency in such diverse areas of chaos theory, it would not be surprising if the combination of negative and positive feedback were a universal feature of all chaos. But in the case of the Lorenz attractor (figure 4.13), we find a counter-example. Each "wing" of the attractor is a positive feedback loop. The trajectory starts inside one wing and moves out. As we get far enough out, the trajectory is captured by the opposite wing, and now the entire operation repeats in the reverse direction. In the car driving analogy (graphed in figure 4.14), we could model the Lorenz attractor as a reckless driver with a positive feedback loop on a divided highway. As he swings wider and wider, he eventually turns perpendicular to the lane, crosses the divider, and starts back in the reverse direction on the other side, where the same operation takes place.

An even easier model would be the game of hot potato. Here we toss a ball and, under the pretense that it is burning our hands, are compelled to toss it higher and higher each time. Finally it gets tossed too far out, and our partner catches it, thus allowing our hands to cool while our partner starts the process over again. In Rössler's lonely version, we have no partner and must roll it off the roof to allow our hands to cool. I once asked

Figure 4.13: Phase space portrait of the Lorenz attractor

First 5,000 iterations of the Lorenz attractor, with timestep .01 and Runge-Kutta integration.

dx/dt = sx+ sy

dy/dt = -xz + rx - y

dz/dt = xy - bz

s = 10, r = 60, b = 8/3

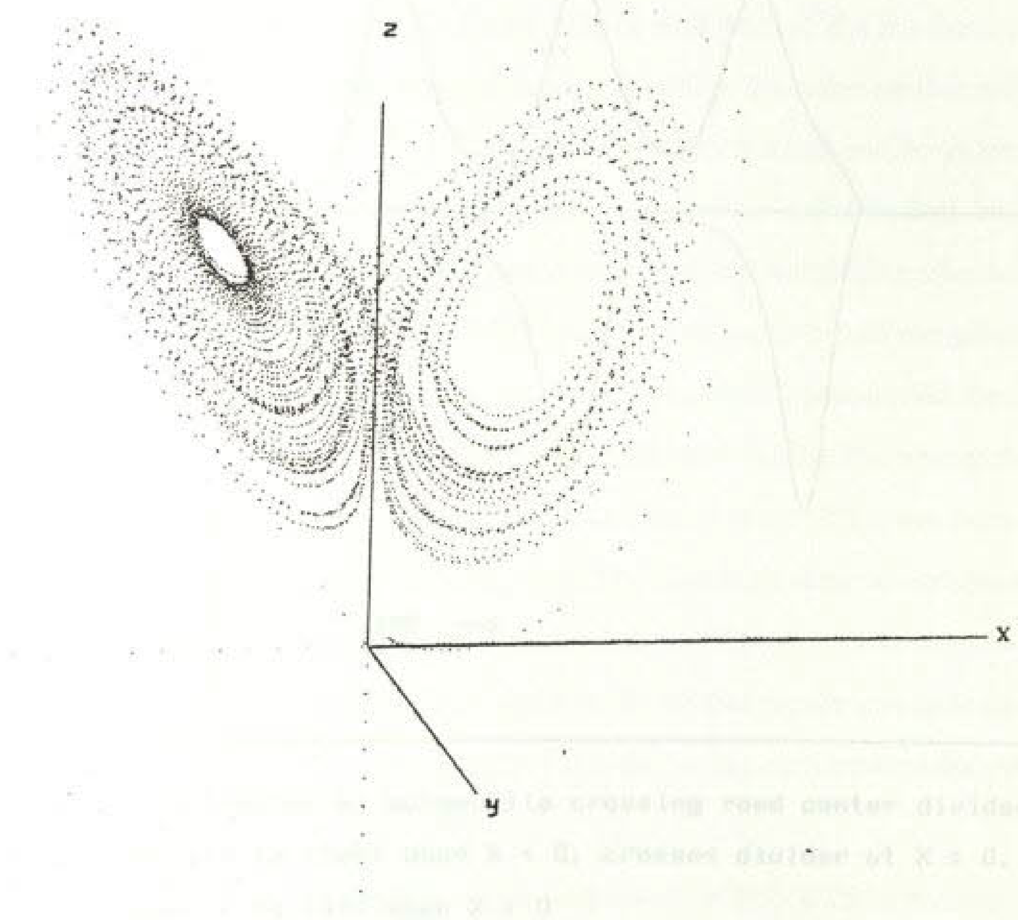
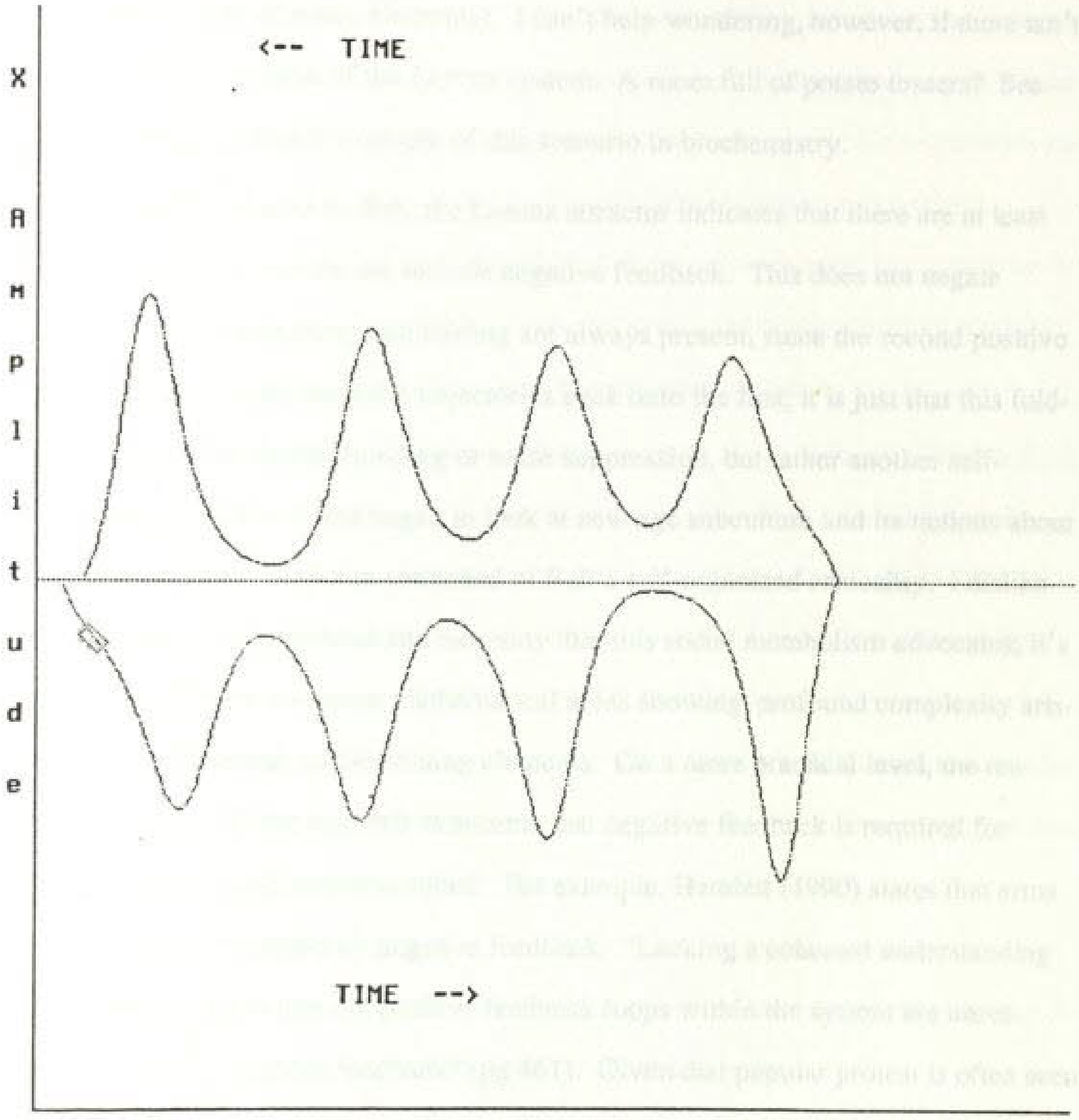


Figure 4.14: Automobile model time series for Lorenz attractor



Lorenz attractor as automobile crossing road center divider.
Car travels to right when $X < 0$, crosses divider at $X = 0$,
and travels to left when $X > 0$

Per Bak if the Lorenz hot potato game (as I described it) would be a counter-example to his claim for the universality of noise suppressing and noise amplifying combinations in chaos. He said that his theory only concerned high-dimensional systems (i.e. the collective self-organization of many elements). I can't help wondering, however, if there isn't a high-dimensional version of the Lorenz system. A room full of potato tossers? See Decroly 1984 for a possible example of this scenario in biochemistry.

Whatever the relation to Bak, the Lorenz attractor indicates that there are at least some chaotic systems that do not include negative feedback. This does not negate Rössler's thesis that stretching and folding are always present, since the second positive feedback loop *eventually* folds the trajectories back onto the first; it is just that this folding mechanism is not due to damping or noise suppression, but rather another self-excited feedback. When I first began to look at new age subculture and its notions about the synthesis of opposites, I was reminded of Bak's self-organized criticality. I dislike the compulsion towards balance and harmony that this social metaholism advocates; it's nice to know that there are some mathematical ideas showing profound complexity arising just from unbalanced, self-deviating elements. On a more practical level, the tendancy for social modeling research to assume that negative feedback is required for bounded systems should be re-examined. For example, Hamlett (1990) states that arms control can only be bounded by negative feedback. "Lacking a coherent understanding of system failure means that the positive feedback loops within the system are unrestrained by effective negative feedback" (pg 461). Given that popular protest is often seen as a positive feedback system (e.g. Kerman 1974, pp. 14-15), such assumptions may carry some unstated ideological claims.

Returning to cybernetic theory, we can only conclude that (as far as has been indicated) chaos requires at least two feedback loops, and at least one of them must be positive feedback. We cannot draw any further specifications for chaos from the simple

negative/positive feedback characterization. However, in terms of a comparison with recursion in digital computation, this result is quite interesting. Recall that it is only 1/F spectra which require the memory allowing a higher level of recursive computation (in Crutchfield a leap from FSA to PDA). Signals with white noise spectra have no correlation between past and present -- there is no memory. Signals with periodic spectra have a perfect correlation between past and present -- memory here is trivial since there is no difference between past, present and future. Chaotic spectra require a non-trivial memory. The system must have some ability to refer to past behavior, but cannot be rigidly locked into its past. Memory in chaotic systems is neither ignored nor slavishly followed; it serves as a chalkboard for computational self-reference.

Chaotic analog systems are, at a minimum, the result of two recursive loops individually characterized (in the presence of a random signal) by white noise and periodic noise; i.e., they are computationally equivalent to FSAs. How is it that together they can leap into a higher level of computation? If we add two FSA's together, we simply get a bigger FSA. There is no way to get a PDA from FSA combinations, but somehow the two analog loops are able to create recursion of a higher order. Neither digital computation theory nor analog feedback theory have, to my knowledge, models for this synergistic phenomenon. For digital computation this would require two machines which separately were equivalent to FSAs, but together created a PDA. For analog theory this would require a notion of feedback at a higher level, a sort of meta-feedback that requires interactive control between two or more ordinary feedback loops.

Mees concludes his essay with an idea which is suggestive of this higher-order feedback control. He reports on a model for control loops in the salivary gland of the fruit fly (Rapp et al, 1980), in which the cells used a frequency modulation to control amplitude variation in a feedback loop.* The authors suggested that this mechanism had evolved for

*Since the frequency modulation loop in this instance does not perform any control operation on

protection against both random and deterministic noise. By encoding one recursive loop in amplitude, and the other in frequency, noise present in the first is likely to be ignored in the second (a claim they support from various directions). Since the frequency waveform was a discrete on-off signal, they chose, unfortunately, to call this a "digital" encoding. In the terminology I am using here, any representation in which a physical parameter varies in proportion to the information it represents is an analog signal. Rate of on-off change is simply another signal parameter; the continuous versus discrete distinction has nothing to do with analog versus digital. But just because a true analog versus digital difference does not exist in this instance doesn't mean that their aren't cases where it does. Rapp et al present an important model for biological communication when they suggest that various recursive loops can communicate through different channels derived from the same signal, and that possibly some of these will exhibit an analog-digital difference. In the following two sections we will consider how these different communication channels and representation forms might be distinguished, and the significance of recursion in such distinctions.

4.5 Towards a Deconstructive Dynamics

Ralph Abraham often takes great pride (as I think he should) in detailing the parallels between his holistic mathematical work in dynamical systems theory, and his holistic social work in the counter-culture of the 1960s. The phase space portrait for an equation seems to take all of the bits and pieces of various signal characterizations and suddenly fit them together as a seamless whole, just as the 1960s youth subculture took bits and pieces of suppressed social activity -- organic gardening, political protest, etc. -- and suddenly had an eclectic but coherent social movement. According to the counter-culture,

the amplitude loop, but simply aids in the intracellular transmission of its waveform, this would only be a degenerate case for the kind of higher-order feedback I had in mind. But it makes the encoding differences particularly clear.

oppression was based on fragmentation and scientific reductionism, and by seeing things whole, one saw through the reductionist illusion and toward a holistic liberatory vision. Since my own interest in dynamics occurred during the postmodern era, I am not surprised that my own approach bears more resemblance to Barthes than to Bateson.

According to Roland Barthes, a radical literary theorist, a text should never be thought of in terms of its transparent communication of some aspect of reality, or a transcendent "author's intent." Rather, any text is an entire field of meanings, none of them "authentic" since they all depend more on the shaping of representation than on what is purportedly represented. The supposed author is but one of many shapers. Liberation for Barthes involves not the emergence of some holistic, authentic reality out of fragmented illusions, but the acknowledgement of the plurality of fragments comprising a representation which was oppressive in its illusion of wholeness. This is, by the way, quite controversial for modernist political activists. Its one thing to expose Big Brother's authenticity as mere illusion, and quite another to demand that all claims to authentic wholeness, including our own, be ended.

In a similar way, I like to think about nonlinear dynamics not as the revelation of the one true phase space object, the abstracted real essence that lies beyond our fragmented illusions, but rather a tool kit for constructing representations that we find useful (for learning, loving, creating, etc.). Like Barthes, I am more interested in increasing our access to the components of the construction than in efforts to make all the components come together, and I suspect that when they are put all together, some information about the components, or at least about the 'constructedness' of the whole, is lost. In this section I will briefly discuss the usual method for exploring dynamical systems, and describe a possible option in the way we look at its representations.

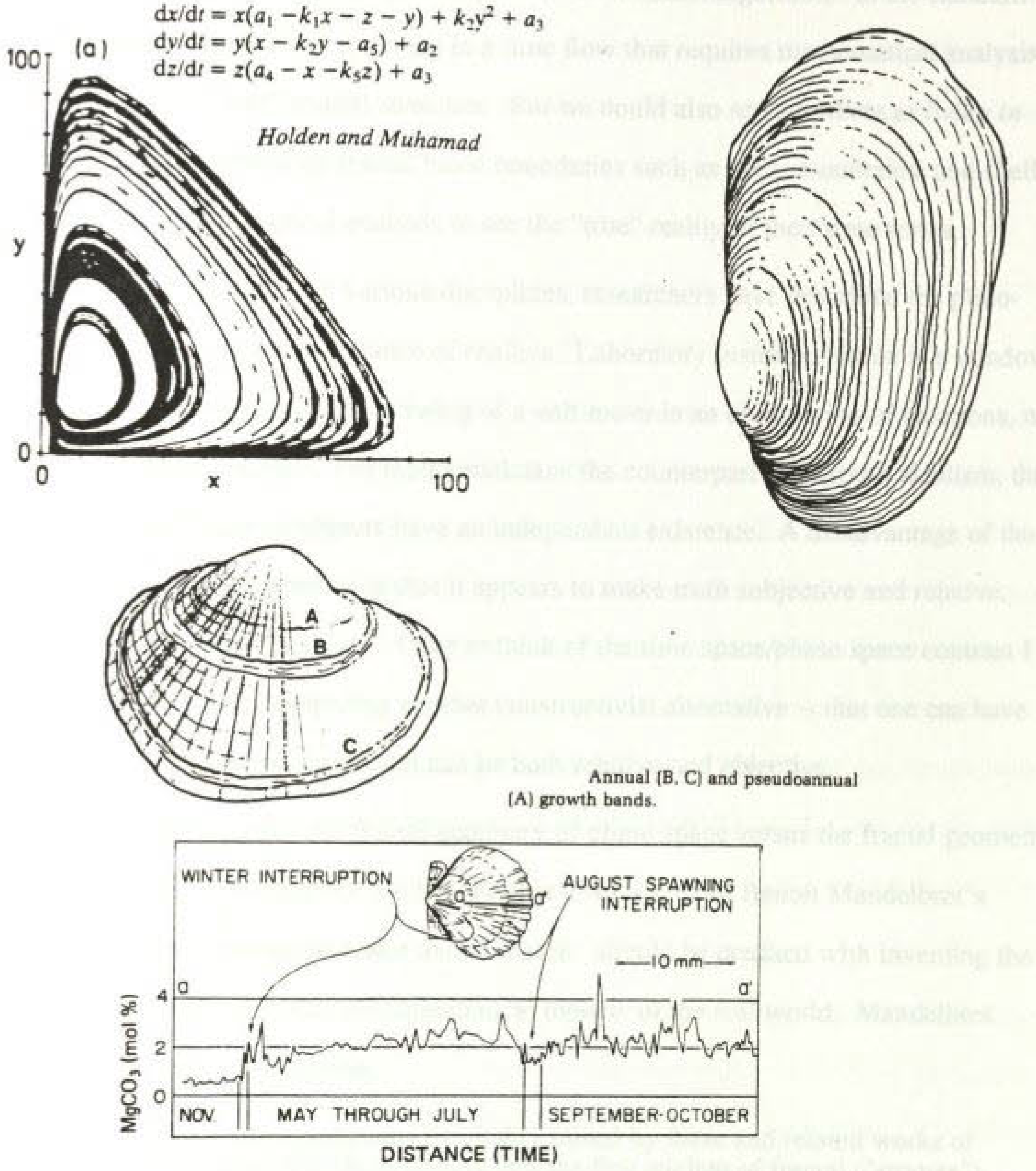
In an empirical study, where phase space portraits and model equations are often the goal, a dynamicist will usually be given data in which the amplitude of some parameter

varies over time. The first step is to ask if it is worth looking at. If it turns out to be white noise, then the chances are poor; if it is something like 1/F noise, then the chances of finding a deterministic equation are much better. A more sophisticated test would determine the minimum size ("embedding dimension") for a phase space that could hold all the variation this signal produced. The Lorenz attractor, for example, is in a three dimensional phase space. Since the attractor is a fractal -- that is, it has a fractional dimension (a cross section of the "wing" shows a Cantor-like structure) -- the dimension of the attractor itself is actually less than three (but more than two).

"Reconstructing" an attractor -- a term that conveys the idea that the time series is the product of a real, original attractor -- can often be carried out by a simple algorithm sometimes referred to as the "method of delays." Here a window is moved across the time series, and the set of points that appear each time the window is moved is taken as the coordinate locations for a single point in phase space. A three-dimensional phase space would take the first three points in the time series (points 1 to 3) as one point in phase space, then points 2 to 4 as another, 3 to 5 as another, and so on. The result is that the signal is sort of folded back on itself, so that the time series correlations are allowed to match up with each other.

The image in figure 4.15a is a phase space portrait of an attractor, but its similar companion in 4.15b is the inside of a bivalve shell. Shells have become popular objects for computer graphics simulation, since they can be easily produced and since their graphics equations are nicely related to the biological dynamics governing real shells. In other words, shells can be grown on the screen in ways that parallel their growth in the ocean. If, instead of a spatial map, we wanted the time series for this growth -- a signal reflecting the peristaltic waves of the mollusk's mantle as it lays down layer after layer of calcium -- we could take the coordinate locations for series of points on the shell, and use those as successive time series points. If successful, then we might feel that our

Figure 4.15: Comparison of phase space and time space objects



Time series comprising shell growth (Rhoads and Lutz, 1980) can be extracted from shell structure; conversely phase space reconstruction of time series produces shell structure.

mathematical model has abstracted a deeper reality from our limited sense data. But this process has simply reversed the phase space reconstruction algorithm. In the standard analysis, we view ourselves as living in a time flow that requires mathematical analysis to reconstruct the "true" spatial structure. But we could also see ourselves as *living in phase space,* surrounded by fractal basin boundaries such as trees, mountains, and shells, and in need of mathematical analysis to see the "true" reality of their time series.

In science studies from various disciplines, researchers have described the philosophic (or at least rhetorical) stance of *realism.* Laboratory instrumentation is a window on "what is really out there." The swing of a volt meter is an observation of electrons, not mere mechanical behavior. For mathematicians the counterpart is Platonic idealism, the notion that mathematical objects have an independant existence. A disadvantage of the usual constructivist alternative is that it appears to make truth subjective and relative, rather than unitary and absolute. I like to think of the time space/phase space contrast I have just described as illustrating another constructivist alternative -- that one can have an absolute without unity; that truth can be both relative and objective.

This choice between the fractal geometry of phase space versus the fractal geometry of time space is at the center of the historical controversy over Benoit Mandelbrot's work. Mandelbrot detractors insist that Poincaré should be credited with inventing the use of non-differentiable sets in mathematical models of the real world. Mandelbrot (1982) makes a finer distinction.

> Let me answer some questions inevitably raised by these and related works of Poincaré. Yes and No: He definitely was the first student of fractal ("strange") attractors. But nothing I know of his work makes him even a distant precursor of the fractal geometry of the visible facets of Nature (pg 414).

For Mandelbrot, the fractal aspects of physical structure are at least as important as fractals in phase space structure. Just as mountain ranges can be characterized by a fractal dimension, Mandelbrot draws on the work of R.F. Voss and others to characterize time

series as fractal curves. "Fractal dimension of a signal" thus has two very different meanings. For some it means the fractal dimension of the phase space attractor. For others it means a direct measure of the irregularity of the time series waveform. These two are kept quite distinct (quite possibly for the reason I like to bring them together, because the combination contests idealism). For example, in Peitgen and Saupe's *Science of Fractal Images,* there is a chapter by Voss on the fractal dimension of the time series waveform, and another chapter by R.L. Devaney on the fractal dimension of phase space objects, but nothing in the entire text that discusses a relation between the two.

Mathematicians often tell me that I shouldn't expect there to be any relation, and they usually back this up with two objections. First, they note the smoothness of the low dimensional chaos waveforms. "Sure it's aperiodic," they say, "but its not a non-differentiable curve." Smoothness, however, can also be matter of perspective. In figure 4.16 we see successive compressions of the waveform produced by the Lorenz attractor. The more waveform we squeeze into this small space, the more irregular it becomes. This still leaves an open question as to whether this kind of irregularity can be characterized by a fractal measure. Does it converge toward the approximation of some particular fractal curve in the compression process? From my own experiments, this does seem to be the case (figure 4.17).

It may be that the invariance measures typically used on fractals do not apply here. On the other hand, the waveforms that Voss and others typically use in their work have neither exact self-similarity nor statistical self-similarity, but are self-affine (Mandelbrot 1985), which means that there will be different scaling properties in different directions, and different dimensional measures depending on the method used (e.g. box versus compass dimension).

If this first objection is correct, the measure of fractal dimensions for time space waveforms will still be valid for high dimensional chaos. The second objection is that

Figure 4.16: Successive compressions of the Lorenz x-axis time series

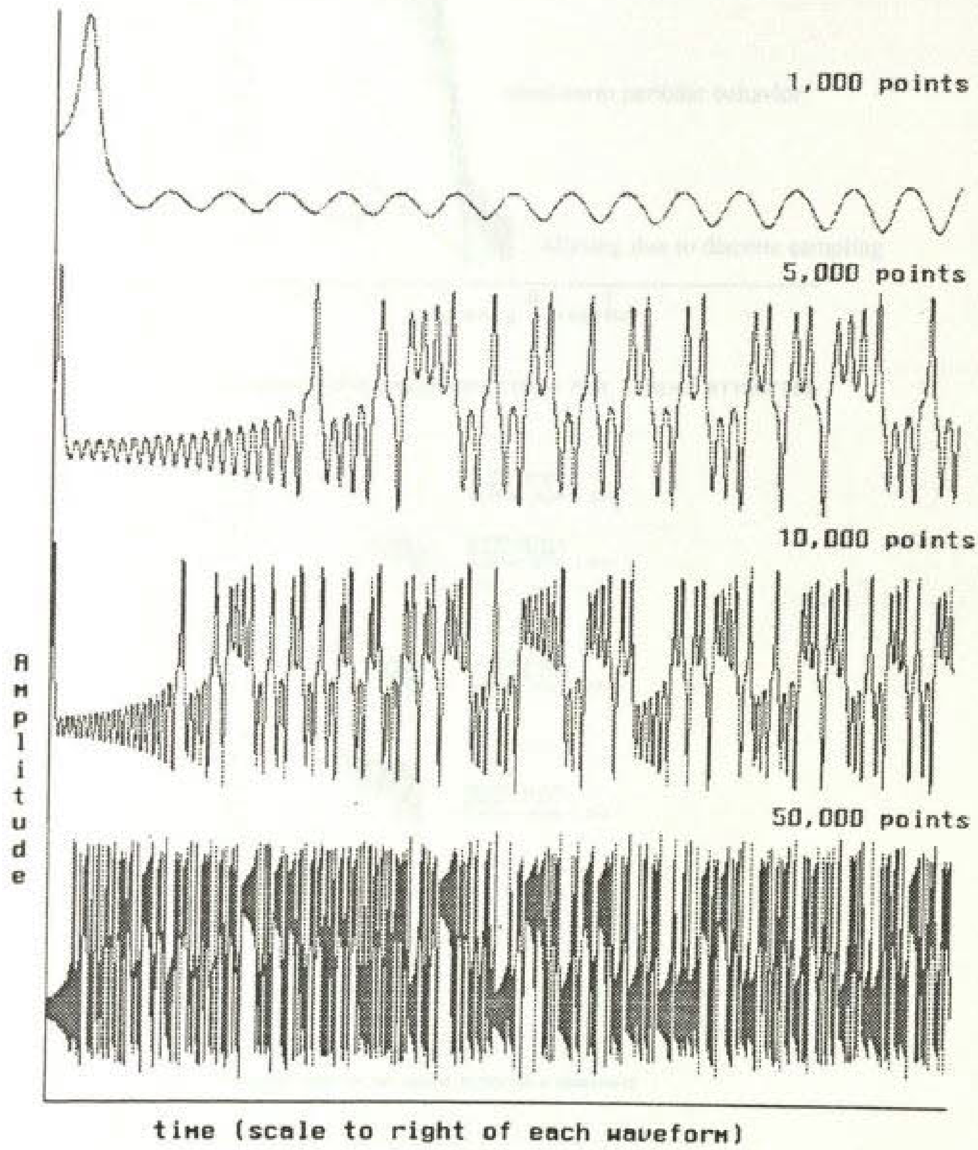
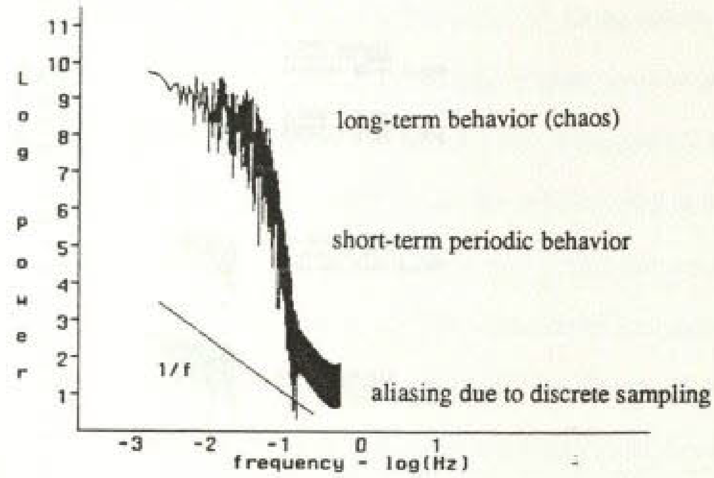
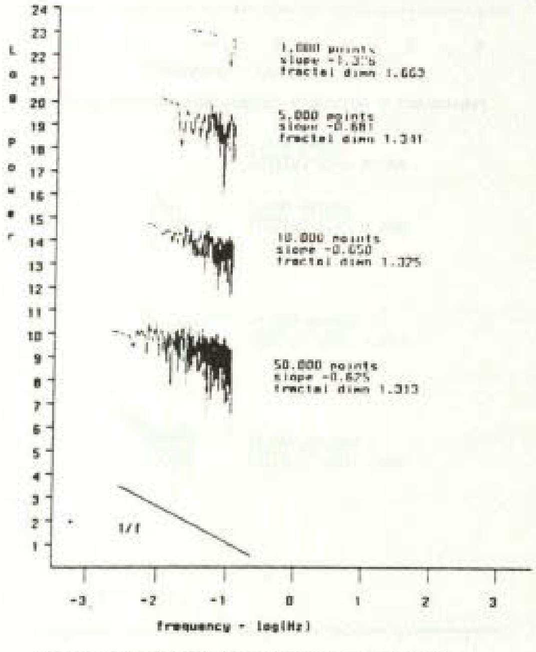


Figure 4.17a: Convergence of spectral slope for Lorenz time series



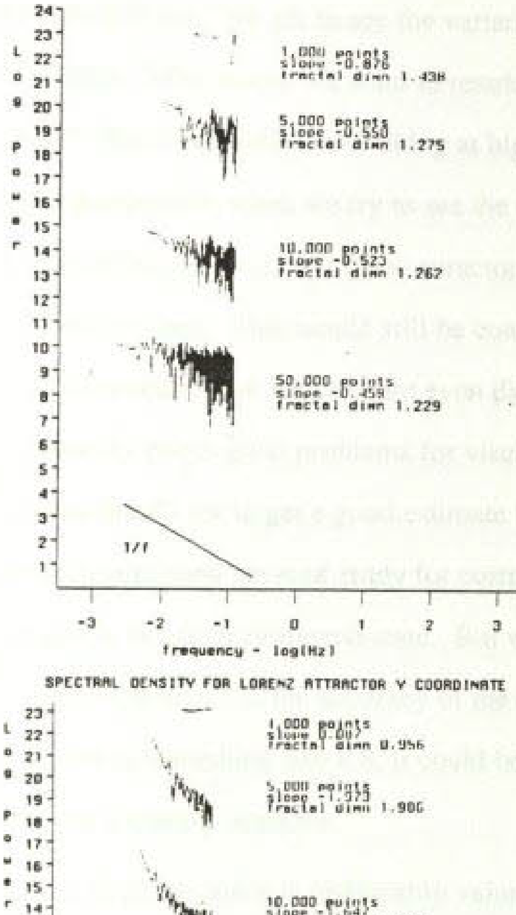
X COORDINATE POWER SPECTRUM FOR LORENZ ATTRACTOR



SPECTRAL DENSITY FOR LORENZ ATTRACTOR X COORDINATE

Spectra for long-term behavior of Lorenz attractor waveforms. Successively longer samples do not vary randomly, but appear to converge to a single value.

Figure 4.17b: Convergence of spectral slope for Lorenz time series



Spectra for long-term behavior of Lorenz attractor waveforms. Y and z axis waveforms also appear to converge to a single value.

too much information is lost by only looking at the variation of one parameter. "In phase space," the mathematicians tell me, "we get to see the variation along every axis of the attractor, all at the same time. Why would we want to restrict ourselves to looking at variation along one axis?" But if we really are looking at high dimensional chaos, then we don't have much of a perspective when we try to see the whole thing at once. For example, studies of human EEG (Basar 1990) show attractors which can require a phase space of greater than 10 dimensions. This would still be considered low dimensional chaos (as opposed to 100 dimensions, at which point even die-hards would start calling it high dimensional), but already poses great problems for visualization or equation formulation. Usually researchers simply try to get a good estimate for this embedding dimension, and there are certainly profound areas of study for correlating changes in this global attractor size with changes in behavior or mental state. But what about the information lost by taking this global perspective? If the accuracy of the dimension measure is to the nearest 0.3, and the measure is something like 8.8, it could be a whole number -- we don't even know if we have a chaotic attractor.

The idea of attractors in phase space is undeniably valuable, and crucial to my own particular interest in the production of waveforms by recursive loops. But I am unconvinced that phase space objects can only be useful from a global approach. Returning to our image of the Lorenz attractor for a moment, we can see that this three dimensional phase space has, of course, three axes. In Lorenz's original model, these represent (indirectly) three physical variables of interest, such as temperature and wind velocity. If we look at the time series waveform for just one of these variables, it can't tell us what the other variables are doing, but we could ask about its own signal characteristics. Suppose the 10 dimensional phase space of the EEG also has some axes of particular interest. It may be, for example, that subtle changes in the waveform corresponding to axis 5 can predict the onset of epileptic seizures. By using the approach of Mandelbrot and Voss,

taking the fractal dimension for the waveform of the one axis, we might be able to retrieve information that is lost to the global perspective.

One problem with the global reconstruction approach is that we have no guarantee that our invented axes will happen to line up with the most useful variables (although one axis will be the original time series, and the others will be orthogonal to it). Typically this is not a concern, since, as mentioned above, the embedding dimension for the attractor as a whole is very useful. But rather than reconstruct one global dimension, we can deconstruct the attractor into many different dimensions, each associated with the slice of phase space from one axis. This deconstructive dynamics maintains the idea of a phase space object, but lets us consider, in a quantitative fashion, many different 'cuts' into this shape.* Since the axis may be at any orientation, there is just as little guarantee that it will coincidentally be a useful one, but the variability allows experimental and theoretical guidance for any particular system. For example, it may be that the two best variables to examine are from two different (not just orthogonally transformed) coordinate systems (in which case the variables may have some kind of mutual correlation).

In the next three sections, we will look at an application of this deconstructive dynamics in the waveforms of acoustic communication. The different communication channels within the acoustic signal will correspond to different axes of this high dimensional phase space. In this instance we will examine the waveforms of one particular axis, and see that a measure of their fractal dimension can distinguish between analog and digital representations in this communication.

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*So far I have only mentioned Voss' measure of fractal dimension in the time space waveform as a way of extracting the single axis perspective, but it is also possible to use a phase space representation of such low-dimensional slices. A good example of this deconstructive approach to phase space is the recurrence plot (a two-dimensional projection) used in an analysis of EKG by Gottfried Mayer-Kress and Matthew Kobbe (published through the Santa Fe Insitiute, and SIAM Transactions on "Computers and Cardiology," 1991).

4.6 Fractal Dimension as an Index of the Analog-Digital Continuum.

Since life is fundamentally a self-organizing process, it should be no surprise that it is characterized by self-similar forms. Not only do fractal shapes abound throughout physiological and ecological structures, but the time dynamics of processes which govern these structures also exhibit fractal scaling behavior. When we turn to biological communication systems however, this characterization is complicated by the presence of digital representation. Unlike analog representation, in which the signal parameter changes in proportion to the meaning it represents, digital codes have an arbitrary relation between the physical signal and its meaning. The difference between these representation types can be detected by differences in the fractal dimension of the waveforms.

The analog/digital dichotomy is often confused with other dualisms. The same terms are used by engineers to describe the continuous/discrete dichotomy, and by cognitive scientists to discuss "reasoning by analogy" versus inductive analysis. Here I am using the terms in their original sense, where they were used to discriminate between analog and digital computers (see Dewdney 1985 for an informal introduction to this distinction).

Just as analog computers represented information by their physical structure, rather than through symbol manipulation, analog communication embeds information in the structure of its waveform. It is based on a proportionality between a physical parameter and a semantic parameter. In an analog thermometer for example, the change in the height of mercury is proportional to the change in temperature. One familar biological example would be a smile, where the curvature of the lips change in proportion to the degree of affect expressed. A more precise biological example occurs in the frog retina, where some neurons have a firing rate which (for most of the range) is in linear proportion to the angular velocity of small moving images (Grusser & Grusser-Cornehls, 1976). Of course the proportionality in some analog representation is non-linear; the nature of

the proportionality does not matter as long as it is shared by the communicator and receiver.

Digital representation is equally common; it is based on a code or look-up table of waveform configurations (symbols or symbol clusters) and their assigned meanings (eg a dictionary, the genetic code). Unlike the analog thermometer, the physical structure of the waveforms produced by a digital thermometer are not in any kind of proportional relation to the information they represent. In an analog thermometer, a mercury rise of 7 length units indicates a proportionate temperature rise of of 7. In a digital thermometer, the physical shape of a numeral "7" has no structural relation to the numeric value 7. It is in this sense that a digital signal can be said to be physically "arbitrary:" the relation between meaning and physical structure has been assigned by convention rather than determined by a proportionality. There are, of course, instances where convention happens (whether by analog origins or mere coincidence) to use a structurally analogous waveform -- in the numeral "3" for example, the physical signal is indeed structured according to the information it represents -- and such exceptions will be considered in the models which follow this section.

One familar human example of digital representation would be sign language. I have an Italian friend who delights in subjecting me to gestures whose meanings (while probably disrespectful) remain undecipherable. A more precise example can be found in the motor neurons which open the crayfish claw. Here a specific temporal firing pattern (off-on-on-off) switches on a defense reflex augmentation (Wilson & Davis, 1965). This temporal pattern is independant of the firing rate.

Neurons are a particularly good example because they help to distinguish the analog/digital contrast in the sense used here from its association with the continuous/discrete dichotomy: the neural signals are always discrete but sometimes analog. It should also be clear that the use of analog and digital to distinguish different

kinds of information is not applicable; it is only a difference in the way information is represented. In the two previous examples neurons used analog representation for visual information and digital representation for motor information, but we also find digital representation in some visual system neurons (Lestienne *et al,* 1990) and analog representation in some reflex motor neurons (Burrows & Pfluğer, 1988).

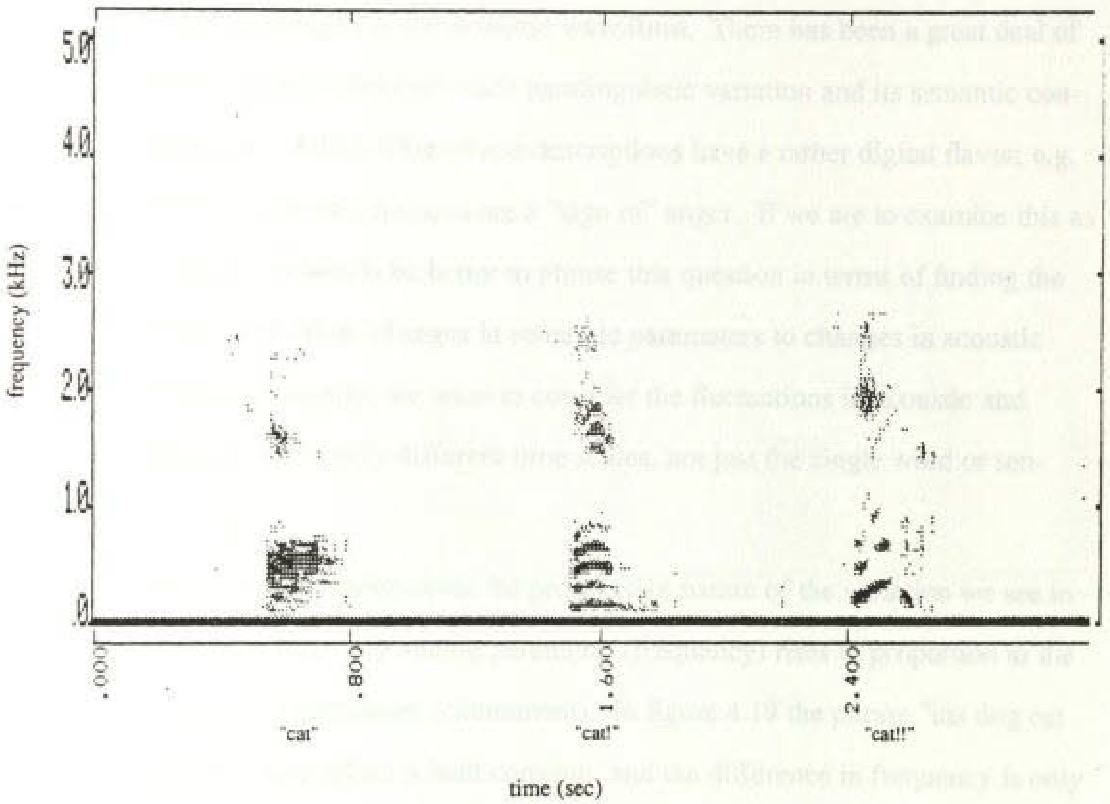
While this distinction between analog and digital representations can be applied to a wide variety of biobehavioral signals, it is rarely clear-cut. Typically there is some complex waveform which varies with many different biological processes, and neither the information content of the signal nor the ways in which different communication channels are embedded in this signal are entirely understood. But even with such limited knowledge, it may be possible to use the generic properties of analog and digital representation to discern their presence.

The following sections will examine the analog/digital distinction in speech waveforms. Here both the information content and the various communication channels have been well explored. A simple mathematical model will allow the difference between analog and digital representation to be measured by computational experiment for spectral density plots, by analytic expression for Kolmogorov complexity, and in spectral measures of fractal dimension for empirical studies of spoken English. The discussion section will return to a generalization of this analysis for a variety of biological communication systems.

4.7 Analog and Digital Representation in Acoustic Communication

Both analog and digital communication are found in the change of frequency over time in human speech. Figure 4.18 shows a graph of frequency over time for spoken American English, with energy as a grey scale (darker = higher energy). In this graph the word "cat" is pronounced three times with increasing levels of excitement ("cat" "cat!"

Figure 4.18: Paralinguistic variation in excited cat calls



"cat!!"). Those features which are invariant constitute the digital component of the word, and those which vary due to the change in emotional emphasis are the analog component.

Watching a real time display of these graphs can give an appreciation for how subtle semantic differences - happy excitement versus curious excitement for example - are encoded by different changes in the acoustic waveform. There has been a great deal of research on the correlations between such paralinguistic variation and its semantic content (c.f. Traünmuller (1988)). Often these descriptions have a rather digital flavor; e.g. researchers ask what acoustic features are a "sign of" anger. If we are to examine this as analog representation, it would be better to phrase this question in terms of finding the proportionalities which relate changes in semantic parameters to changes in acoustic parameters. Most importantly, we want to consider the fluctuations in acoustic and semantic parameters over many different time scales, not just the single word or sentence.

This characterization underscores the progressive nature of the variation we see in the three utterances of "cat:" the analog parameter (frequency) rises in proportion to the increase of the semantic parameter (excitement). In figure 4.19 the phrase "cat dog cat dog cat" is graphed. Here affect is held constant, and the difference in frequency is only due to the digital variation. In this digital code the relation between semantic content and the physical signal is arbitrary. The frequencies for "cat" are higher than those of "dog," but that convention does not imply anything about the differences in meaning - and indeed we find this convention reversed in other languages, such as Spanish (figure 4.20).

One exception to this arbitrariness is onomatopoeia: words which sound like the thing they describe (e.g. "bang"). The time scale for this analog component is, however, rarely longer than a single word. If I get increasingly excited while speaking, my fundamental frequency may be slowly rising through hundreds or thousands of words. There are a few other exceptions, but they also have few instances where the correlation

Figure 4.19: English linguistic variation

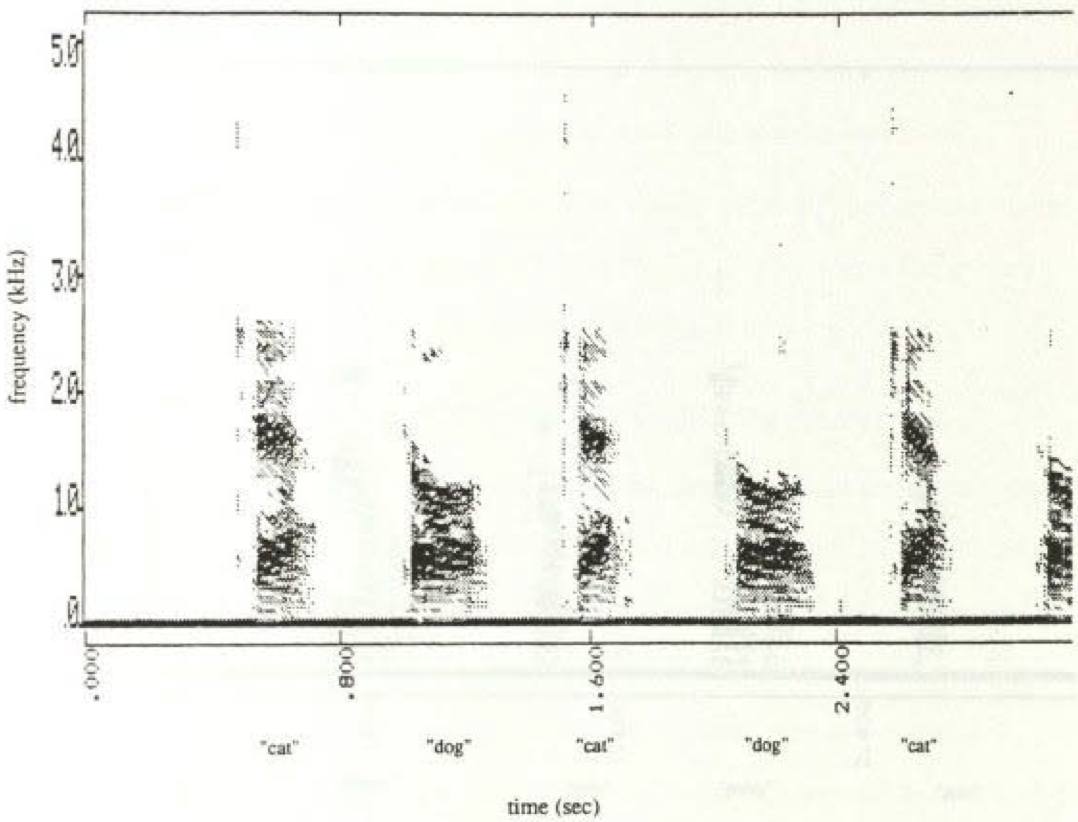
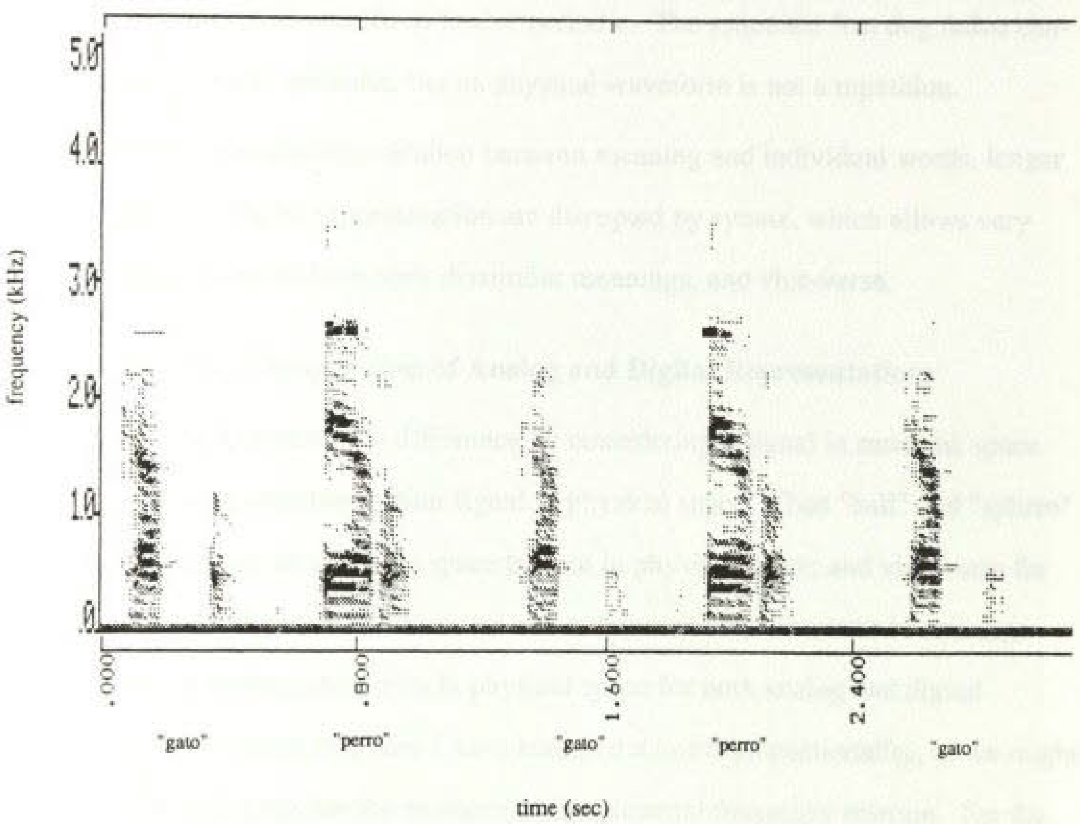


Figure 4.20: Spanish linguistic variation



between semantic parameters and physical parameters exceeds the length of a word.

This arbitrariness is increased by homonyms and synonyns, since they prevent unique mappings between meanings and waveforms ("degenerate coding" in information theory terminology). For example, "cat dog cat dog cat" is not only a periodic semantic sequence, but its physical waveform is also periodic. The sequence "cat dog feline canine" is also semantically periodic, but its physical waveform is not a repetition.

In addition to the arbitrary relation between meaning and individual words, longer term correlations in digital representation are disrupted by syntax, which allows very similar strings of words to have very dissimilar meanings, and vice-versa.

4.8 Spectral Density Comparisons of Analog and Digital Representations

We can formally model this difference by considering a signal in semantic space and its corresponding communication signal in physical space. Thus "ball" and "sphere" would be close together in semantic space but not in physical space; and vice-versa for "ball" and "brawl." Figure 4.21 illustrates a one-dimensional time series in semantic space, and corresponding time series in physical space for both analog and digital representations. For the analog case I have assumed a linear proportionality, as we might find over a restricted range for the excitement-fundamental frequency relation. For the digital case I have assumed a simple code in which values in the semantic signal are represented by arbitrarily (randomly) assigned values in the physical signal, as we might find for the average frequencies of individual words in a sentence.

We can examine the differences in these signals by looking at the energy levels over a range of correlation lengths. Figure 4.22 shows a spectral density plot (by FFT) for the analog and digital waveforms in figure 4.21 (here with more sample points). The analog signal's spectrum resembles the fourier transform for a unit ramp function (which, in fact, it is). Three different examples of arbitrary codes for the digital representation are

Figure 4.21: Analog and digital time series

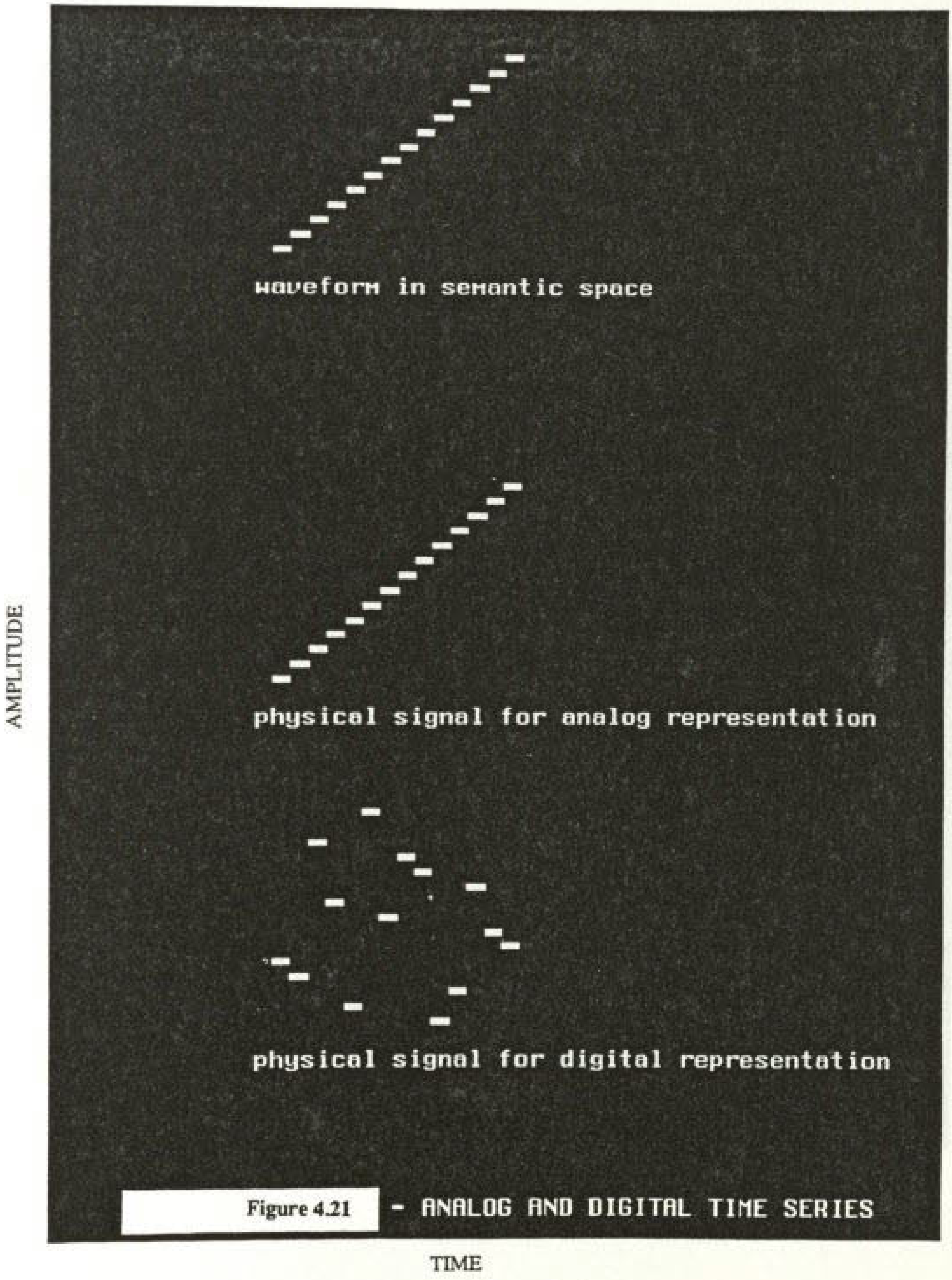


Figure 4.21 - ANALOG AND DIGITAL TIME SERIES

Figure 4.22: Power spectra for analog and digital time series

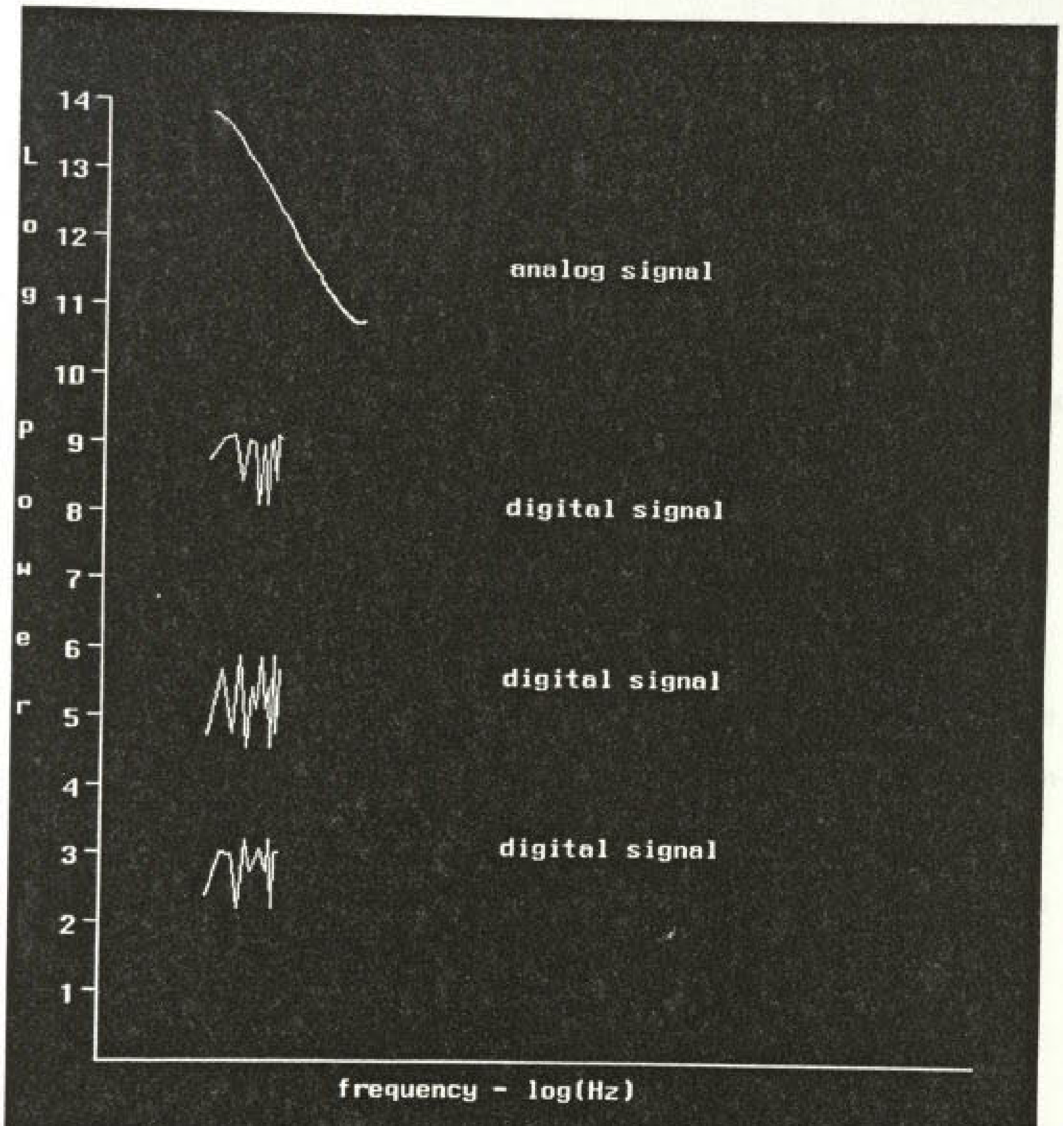


Figure 4.22 POWER SPECTRA FOR ANALOG AND DIGITAL SIGNALS

shown; although their frequency composition varies they all show the same white noise profile.

The information represented in speech is not, of course, always new - in fact, we expect it will always include some repetition. If we consider a unique digital coding for repetition of the same information - as would occur for the same sentence repeated several times - then we would expect something like figure 4.23. Figure 4.24 shows the spectral density plots for these waveforms, with three different codings of the digital representation. The digital signal shows the same sharp low frequency peak, due to the repetition, in each case. The numerous high frequencies here are partly due to Gibbs phenomenon, from the large number of discontinuities. In summary, both the analog and digital representations show a large low frequency component, but this peak is smeared out across a wider band in the digital signal.

Finally, we can add the effects of non-unique digital coding - homonyms and synonyns for individual words, and syntax for strings - for the same repetition. Figure 4.25 shows the same periodic example with a completely different coding for each cycle in the digital case. The spectral density plots for these signals, with three different examples for the digital case, are show in figure 4.26. No large low-frequency component appears for the digital signals in this case. Of course, real communication will not use a completely different coding each time, and we can expect some mixture of unique and non-unique coding.

4.9 Complexity Comparisons of Analog and Digital Representations

The difference between analog and digital representations can also be quantified by complexity. Kolmogorov (1968) has defined the complexity of a symbol string as the size of the smallest program needed to calculate the string; for random strings the complexity is equal to the length of the string. Here we will use the grammar complexity

Figure 4.23: Periodic analog and digital time series

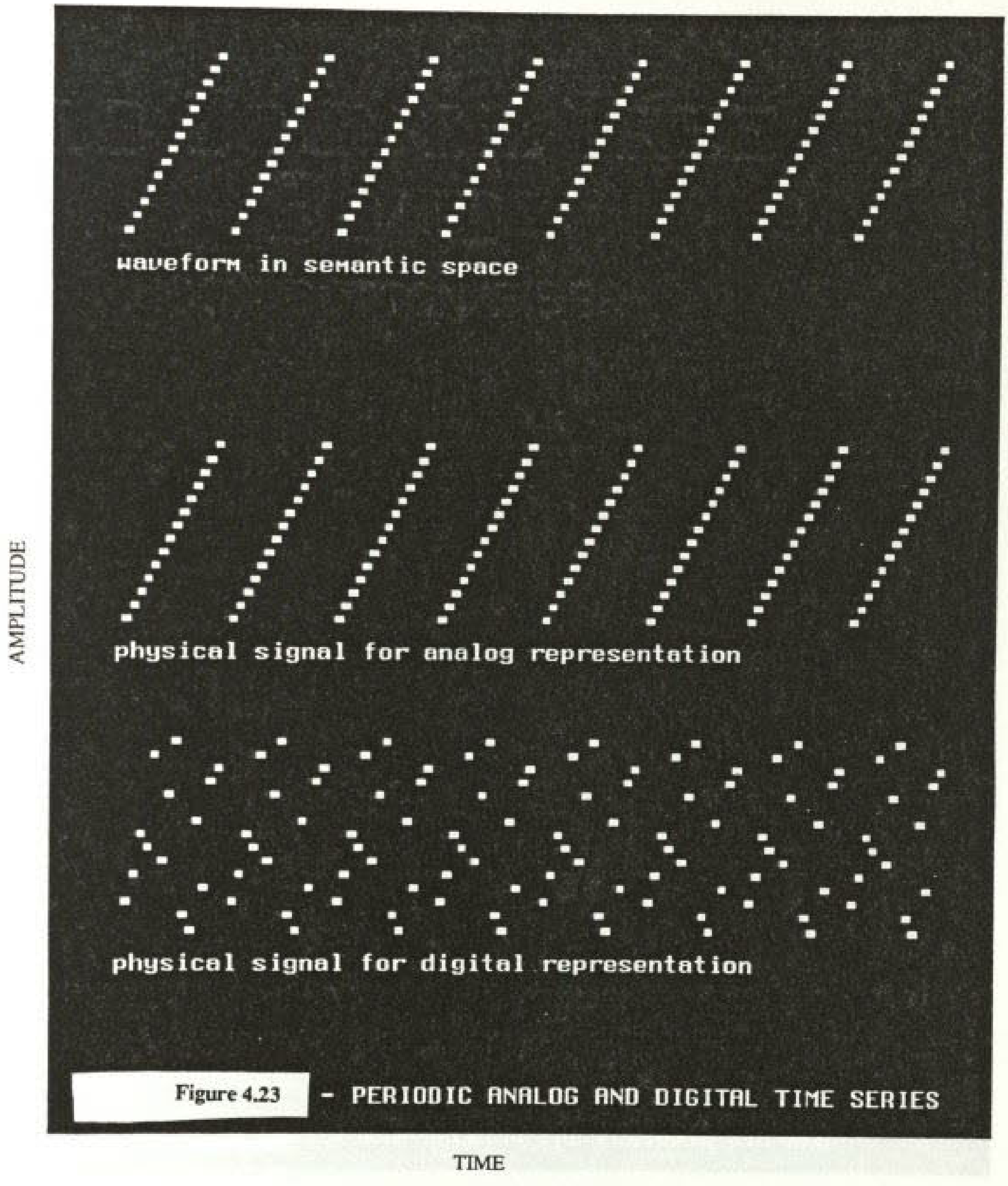


Figure 4.24: Power spectra for analog and digital periodic signals

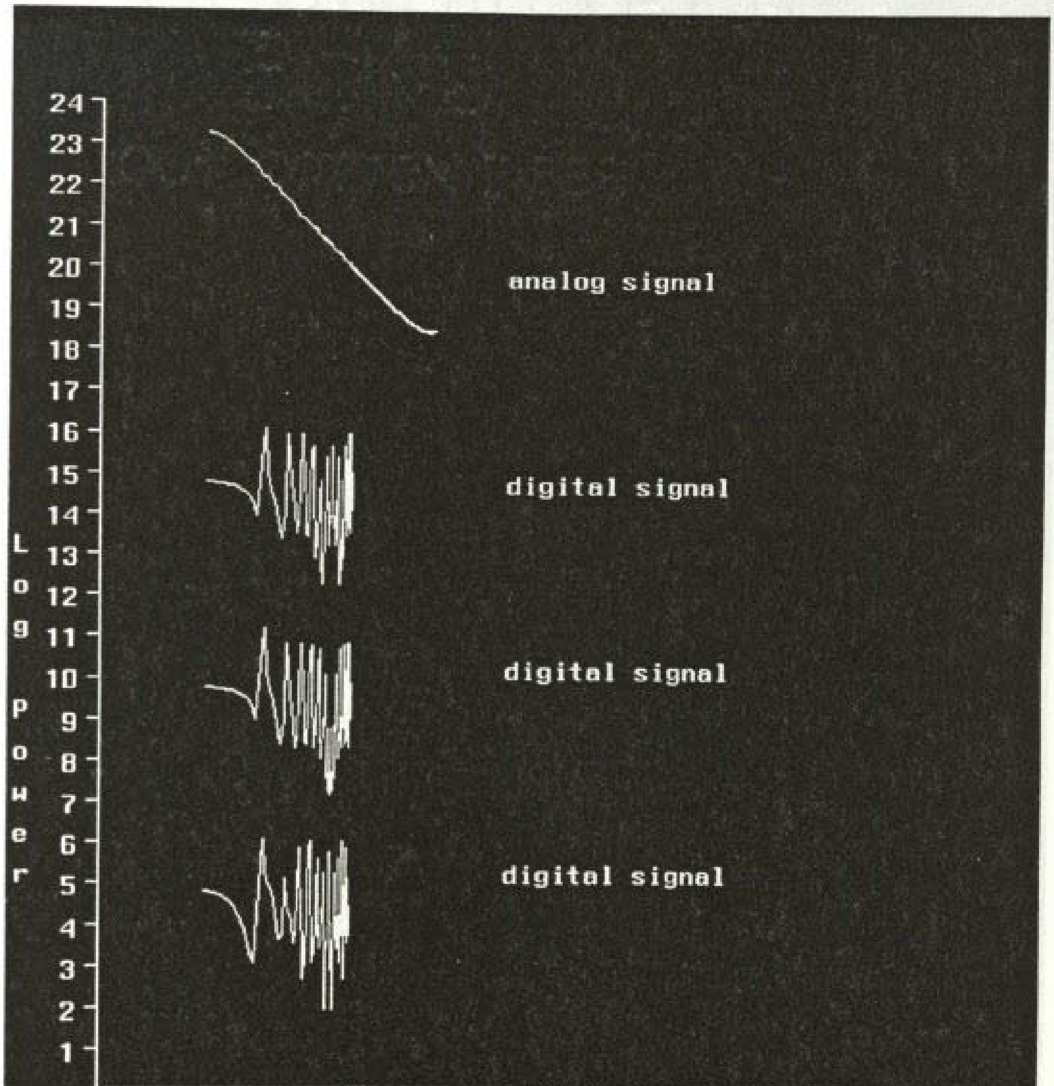


Figure 4.24 - POWER SPECTRA FOR PERIODIC SIGNALS

Figure 4.25: Periodic signal; non-unique digital code

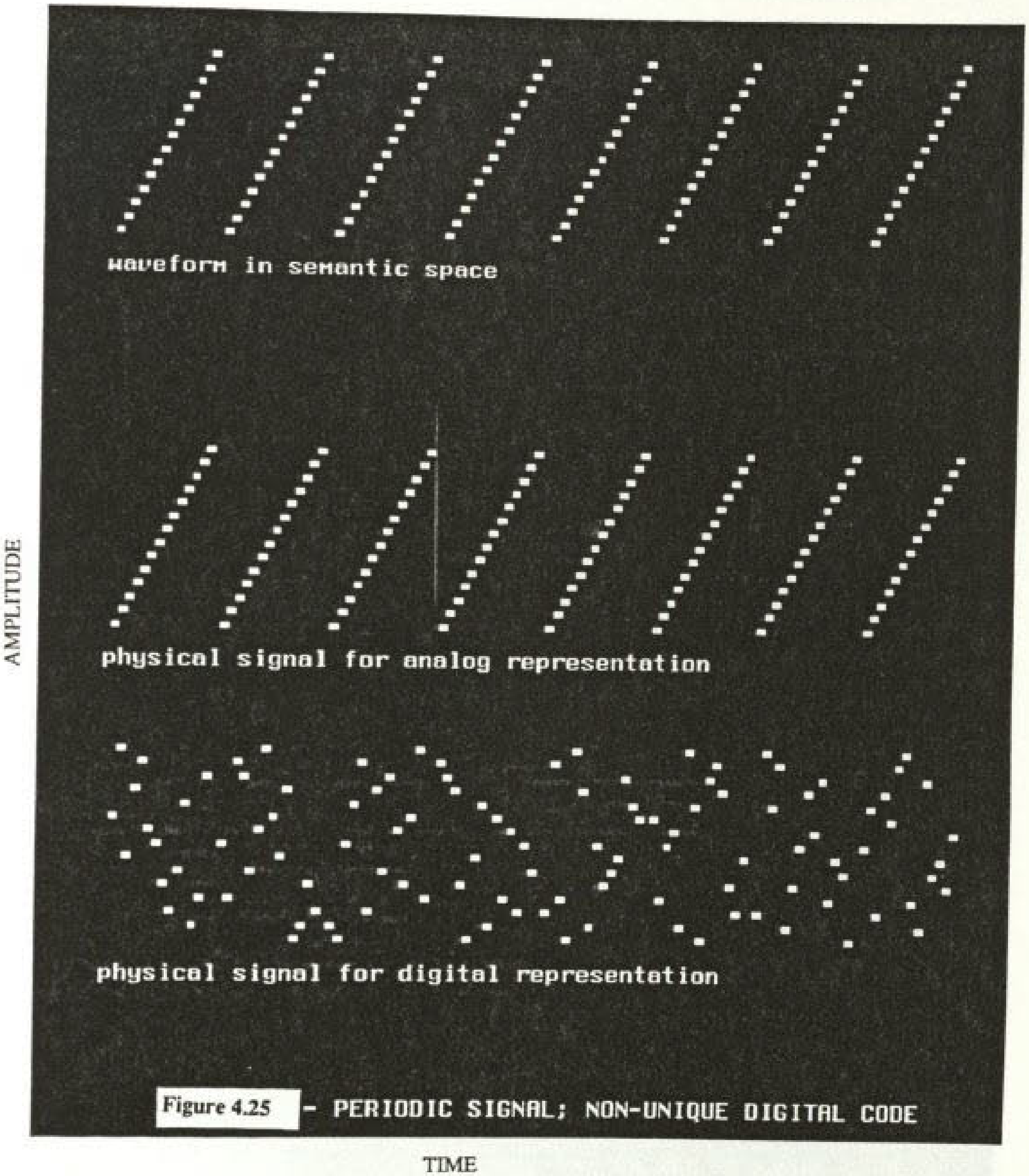


Figure 4.25 - PERIODIC SIGNAL; NON-UNIQUE DIGITAL CODE

Figure 4.26: Power spectra; non-unique digital code

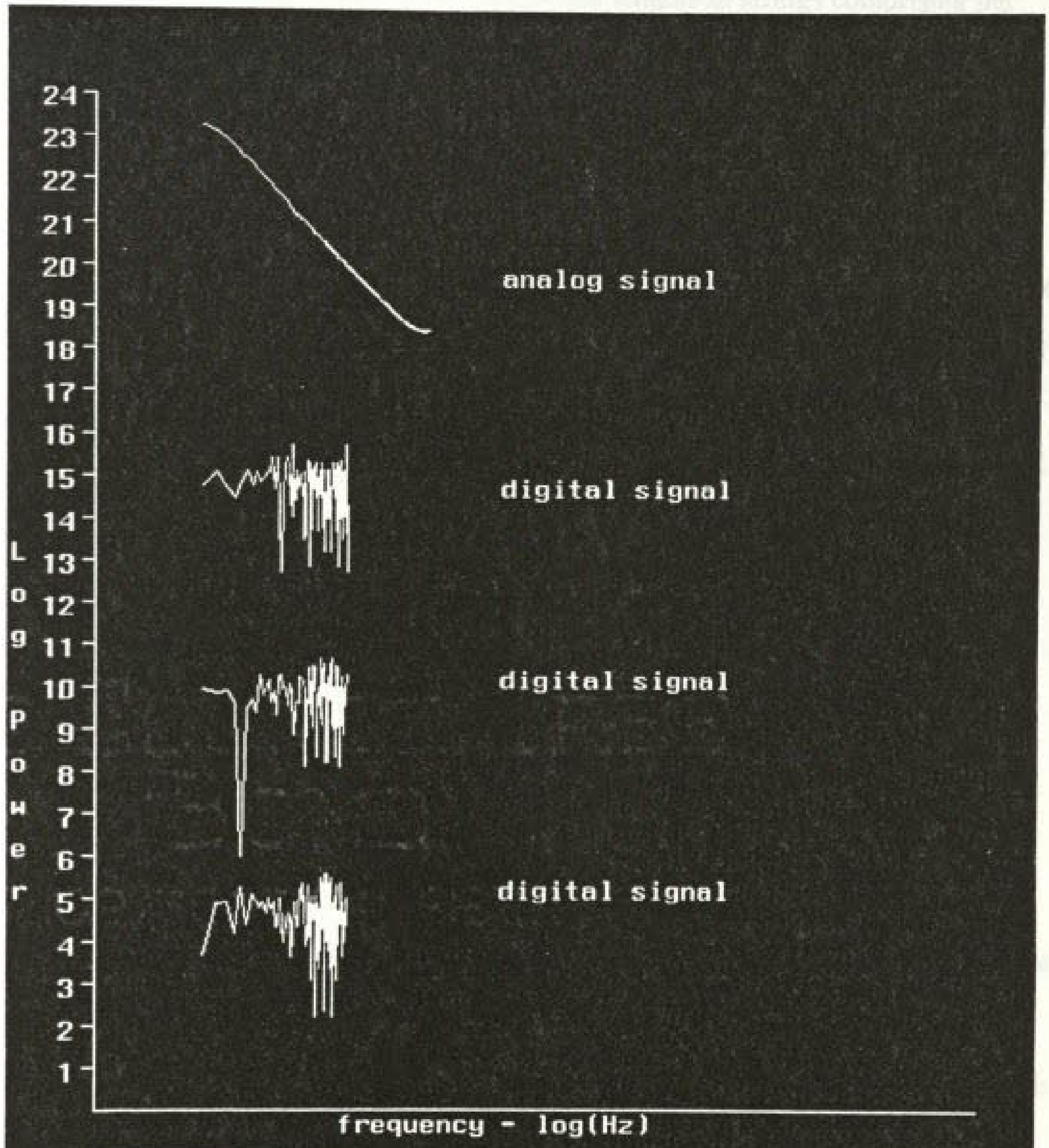


Figure 4.26 - POWER SPECTRA; NON_UNIQUE DIGITAL CODE

defined by Jimenez-Montano (1984):

1) The program consists of a context-free grammar which generates one unique string.

2) The complexity of the program is the sum of the lengths of strings comprising the right-hand side of each production rule.

3) An exception to (2) are those strings consisting of only one symbol; their complexity is equal to $1+\log_2(length)$.

We can convert the point sampled waveforms into symbol strings by using zeros to represent the height of each point and ones to separate the zeros. For a ramp function 8 points long we have the string: 10100100010000100000100000010000000100000000. A periodic wave made of 8 of these ramps, as displayed in the last example, can be generated by the following one-string grammar:

$S \rightarrow e^8$

$e \rightarrow k1jkj1iki1ijkij1ii$

$i \rightarrow jj$

$j \rightarrow 00$

$k \rightarrow 10$

which gives a complexity $K_G=(1+\log_2 8)+24=28$. For the same information with non-unique digital representation the first rule $S \rightarrow e^8$ cannot be applied - a different production rule must be used for each cycle. In general, given the same average complexity within each cycle, N cycles would give $K_G=N+25$ for this digital case. For the analog case $K_G=(log_2 N)+25$. Thus the complexity for non-unique digital representation will increase as a linear function of the length of the signal, but the analog representation of the same information will only increase as the log of the length of the signal. Again, real com-

munication will not give a purely non-unique coding for each repetition, and empirical measures are required to determine the extent to which the arbitrary aspects of digital coding can diminish signal correlation lengths.

4.10 Comparisons of Analog and Digital Representations for Empirical Measures of Fractal Dimension

Both spectral density functions and Kolmogorov complexity can be related to fractal dimension. It is important to understand that "fractal dimension of a time series" is not used here to designate the dimension of a phase space object reconstructed from the time series. It is the fractal dimension of the time series waveform structure, as discussed in section 4.5. For the simple deterministic fractals generated by recursive replacement of a seed shape of N parts by reduction ration r, the "similarity dimension" is given by $logN/log(1/r)$. This value can also be estimated by finding the number of boxes of size r needed to cover the curve ("box dimension"), or the length produced when N rulers of size r are used to traverse the curve ("compass dimension"). The type of curves produced by the time series used in this study are more complex however, in that the vertical (amplitude) and horizontal (time) coordinates scale differently. As previously noted, such "self-affine" curves will produce two different values for box dimension and compass dimension, and cannot be defined by a similarity dimension (Mandelbrot 1985). They are best characterized by scaling properties of their probability measures.

In terms of probability, fractals can be seen as a compromise between order and chance. A shape is "most fractal" when the fractional part of its dimension is near .5. For less random shapes the dimension will increase towards the next highest whole number; for more random shapes the dimension will decrease toward the next lowest whole number. For time series this can be measured by the spectral density function. The fractal dimension of a white noise is 1.0, and the dimension increases for less ran-

dom signals (ie lower Kolmogorov complexity). For continuous spectra with log dependence on frequency F and -2 < slope < 0 the fractal dimension can be measured by β in the spectral density function $\frac{1}{F^{\beta}}$. Here β is in linear proportion to the fractal dimension D_f according to $D_f=(2-\beta)/2$ (see Gardner (1978) for an informal account, Voss (1988) for a more rigorous approach).

As mentioned in the introduction, we can expect fractal waveforms - that is, waveforms with $\beta=1$ - to dominate the *information content* of biological (and social) communications. But the physical *representation* of this information will have a spectral density function which depends on its representation type. Since many representations will be somewhere between analog and digital, we can think of D_f (in this context of 1/F information distributions) as an index of position on an analog-digital continuum.

The initial studies of Voss (1978) suggest a confirmation of this relationship between the analog-digital distinction and fractal dimension. The communication categories used by Voss were instrumental music, music with few vocals, music with many vocals, and speech. The physical parameters were average instantaneous frequency (heard as pitch) for all categories, and an additional test of amplitude (heard as loudness) for speech and instrumental music. Since the frequency of speech contains contributions from both analog and digital components, we can expect long-term frequency time series of speech to have a fractal dimension (D_f) between 1 and 1.5 (i.e. between white noise and 1/F noise). The frequency of music, in contrast, produces long term fluctuations which mimic the fluctuations of affect (Meyer 1956). As the orchestra swells, so do our feelings. In characterizing music frequency as analog representation, we can expect a fractal dimension around 1.5. By adding vocals to music, we can expect fractal dimension to change accordingly -- the more vocals, the lower the dimension. In the case of amplitude time series, we can expect a different result for speech. Long term

changes in speech amplitude reflect emotional intonation ("paralinguistic features"); as analog representation we can expect a tendancy to $D_f = 1.5$. For music, loudness is modulated in analog relations similar to those of pitch, and thus we expect amplitude time series of music to also approximate $D_f = 1.5$.

The data produced by Voss (1978) matches these predictions. Voss found that loudness in both music and speech produces a spectral density close to $\frac{1}{F^1}$ (i.e. D_f=1.5). The spectral density of frequency variations in music depended, however, on the amount of vocals in the music - the more vocals, the lower the β. For speech alone, the spectral density approached $\frac{1}{F^0}$ (D_f=1). Voss drew conclusions from this data which were similar to the distinctions I have discussed here.

Note that Voss has extracted two different time series -- amplitude and frequency -- from what is presumably a large-dimensional phase space. It is paramount in this approach that some knowledge guides the selection of the particular parameter, the "slice" of the phase space, which will comprise the time series to be investigated. In this case it is easy, since we know something about our own communication. Of course, amplitude and frequency are only two of many possible dimensions. Bain (1988) describes the evolution of communication channels in terms which are isomorphic to attractor reconstruction: fluctuations of amplitude are the most primitive, the rate of change of amplitude fluctuation (frequency) was a successive evolution in communication, the rate of change of frequency fluctuation evolved on that substrate, and so on.

Two sets of experiments were conducted by this author to extend these findings of Voss for frequency. The samples of the first set compared a reading of prose, a reading of poetry, and acappella song. Voss did not examine song with all vocals and no instrumental music, but it can be expected that this will have a much stronger analog component than normal speech, since the frequencies in singing are at least partly determined by the

tune. Poetry nicely situates itself between speech and music. In poetry words are picked as much for their sound as for their symbolic meaning. Here the normally accidental, short term associations such as onomatopoeia are carefully orchestrated; together with rhyme, meter and other physical aspects of the waveform they are used to produce long term physical signal correlations. Thus we can expect poetry to be positioned mid-way between analog and digital. The first five samples (of three categories each) were produced by a male English speaker with a west coast Jewish-American accent (author). The sixth sample was produced by a female English speaker with a west coast African-American accent. The last sample was produced by a female Mandarin Chinese speaker. Since Mandarin Chinese is a tonal language, Voss (1978) suggests that it will have stronger relations between its physical structure and informational structure. My own expectation is that all human languages are equally digital, and that none will not show a strong analog relation.

The second set of experiments compared Rap music with Reggae music. The samples chosen for both types of music were heavily vocal, but differed in the way the vocals were sung. Rap music is notorious for a flat, non-melodic vocal style. It was expected that Rap music would have a lower fractal dimension than Reggae.

A third experiment examined cetacean communication. In my previous work (Eglash 1984) a review of behavioral and neurological evidence strongly suggested that cetacean communication was primarily analog rather than digital. Research on killer whales (Bain 1988, Kirkevold and Lockard 1986) indicates that their communication may have some digital representation as well as analog, while the "songs" of humpback whales (Payne 1971) appear more purely analog. This experiment compared a 15 minute sample from Payne's *Song of the Humpback Whale* record with a 7 minute sample of killer whale vocalizations, recorded in the Johnstone strait by students from the UCSC Long Marine Lab.*

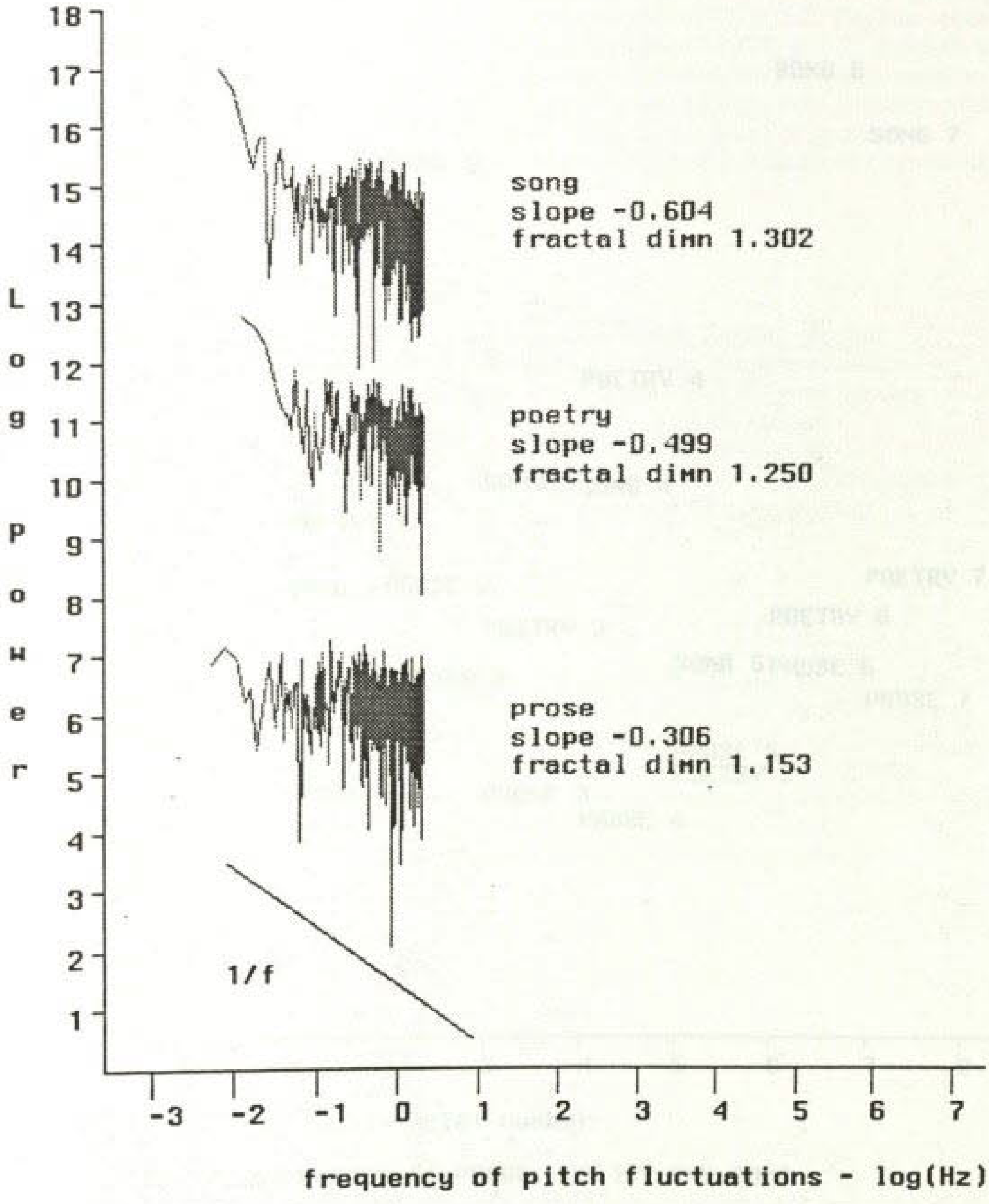
*David Bain, Kelly Neumann, David Briggs, Denise and Scott Norris, Janet Waite, and myself.

Initial recordings were made with a Sony TCD-5M and transferred to a RAYCAL for slow-down. Short term plots on an HP5451C spectrum analyzer indicated that aliasing distortion could be kept below 6% for sampling rates of 48 Hz for the human and humpback whale samples, and 192 Hz for killer whale samples. An HP5427 frequency counter was used to transform the audio recordings into a frequency time series (with the above sampling rates), which were then collected by an Apple IIe. The time series were transferred to an IRIS workstation, where an FFT produced spectral density plots. The spectra were truncated at a fluctuation rate of about 0.5 Hz to reduce error due to aliasing and Gibbs distortions, and this slope was calculated by least squares regression.

4.11 Experimental Results

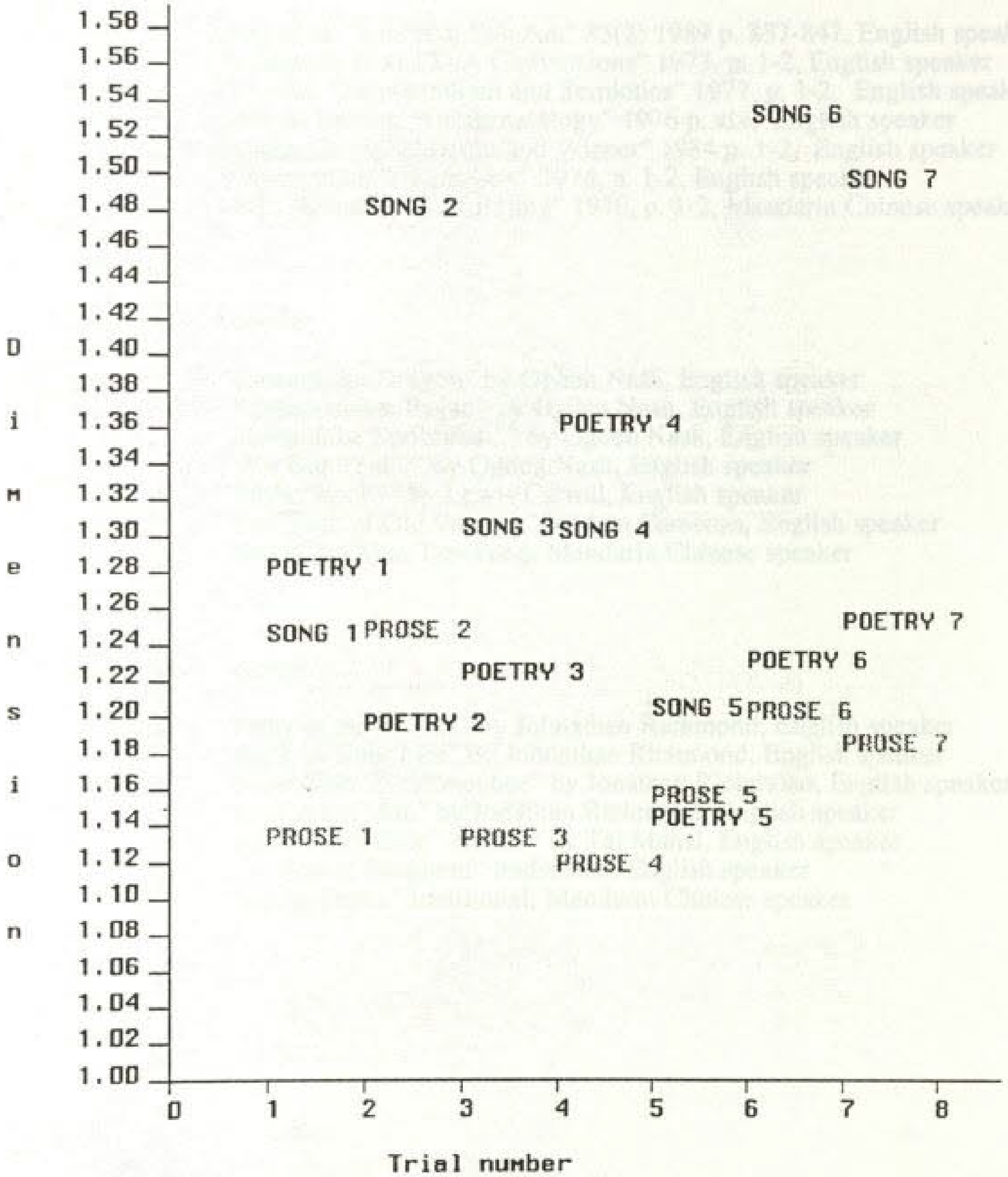
A graph of the spectral densities from one of the samples from the first experiment set is shown in figure 4.27. The increase in the long-term correlations (amount of power in the low frequencies) for more analog signals can be observed. Figure 4.28 shows a graphical summary of all 7 samples, and the sample sources are summarized in figure 4.29. Figure 4.30 shows a graphical summary of the samples in the second experimental set, and its sources are summarized in figure 4.31. Figure 4.32 shows the spectral densities from the cetacean vocalizations. Results in all three experimental sets matched the expected results, although there was considerable variation within the categories of the first experiment. Statistical significance was measured by the Wilcoxon rank sum test. The poorest significance level was at .05, for discrimination between prose and poetry. Discrimination between poetry and song was at .025. Prose versus song and Rap versus Reggae were significant at better than .01. The Mandarin Chinese carried the same relation as did the English samples.

Figure 4.27: Power spectra of English prose, poetry and song



SPECTRAL DENSITY FOR ENGLISH SPEECH

Figure 4.28: Fractal dimension of prose, poetry and song



FRACTAL DIMENSION OF PROSE, POETRY AND SONG

Figure 4.29: Sources for acoustic samples in set 1

Prose

Fractal Dimension	Source
1.115	May et al, "J Acoust Soc Am" 85(2) 1989 p. 837-847, English speaker
1.131	Malmstadt et al, "D/A Conversions" 1973, p. 1-2, English speaker
1.130	Hawkes, "Structuralism and Semiotics" 1977, p. 1-2, English speaker
1.244	Spivak, intro to "Grammatology" 1976 p. xix, English speaker
1.153	Heims, "Von Neumann and Wiener" 1984 p. 1-2, English speaker
1.200	Wasser et al, "Chem One" 1976, p. 1-2, English speaker
1.182	PRC, "Geography of Bejing" 1970, p. 1-2, Mandarin Chinese speaker

Poetry

Fractal Dimension	Source
1.141	"Custard the Dragon" by Ogden Nash, English speaker
1.193	"Dispassionate Pagan" by Ogden Nash, English speaker
1.250	"Lines to be Scribbled..." by Ogden Nash, English speaker
1.280	"The Big Tent..." by Ogden Nash, English speaker
1.359	"Jabberwocky" by Lewis Carroll, English speaker
1.228	"The Face of Old Woman" by Ann Cameron, English speaker
1.221	"Snow" by Mao Tse-Tung, Mandarin Chinese speaker

Song

Fractal Dimension	Source
1.302	"Party in the Woods" by Johnathan Richmond, English speaker
1.243	"Back in Your Life" by Johnathan Richmond, English speaker
1.201	"Buzz Goes the Honeybee" by Jonathan Richmond, English speaker
1.479	"Ice Cream Man" by Jonathan Richmond, English speaker
1.300	"Bet You're Goin' Fishin'" by Taj Mahal, English speaker
1.529	"On Top of Spaghetti" traditional, English speaker
1.455	"Bejing Opera" traditional, Mandarin Chinese speaker

Figure 4.30: Fractal dimension of Rap and Reggae

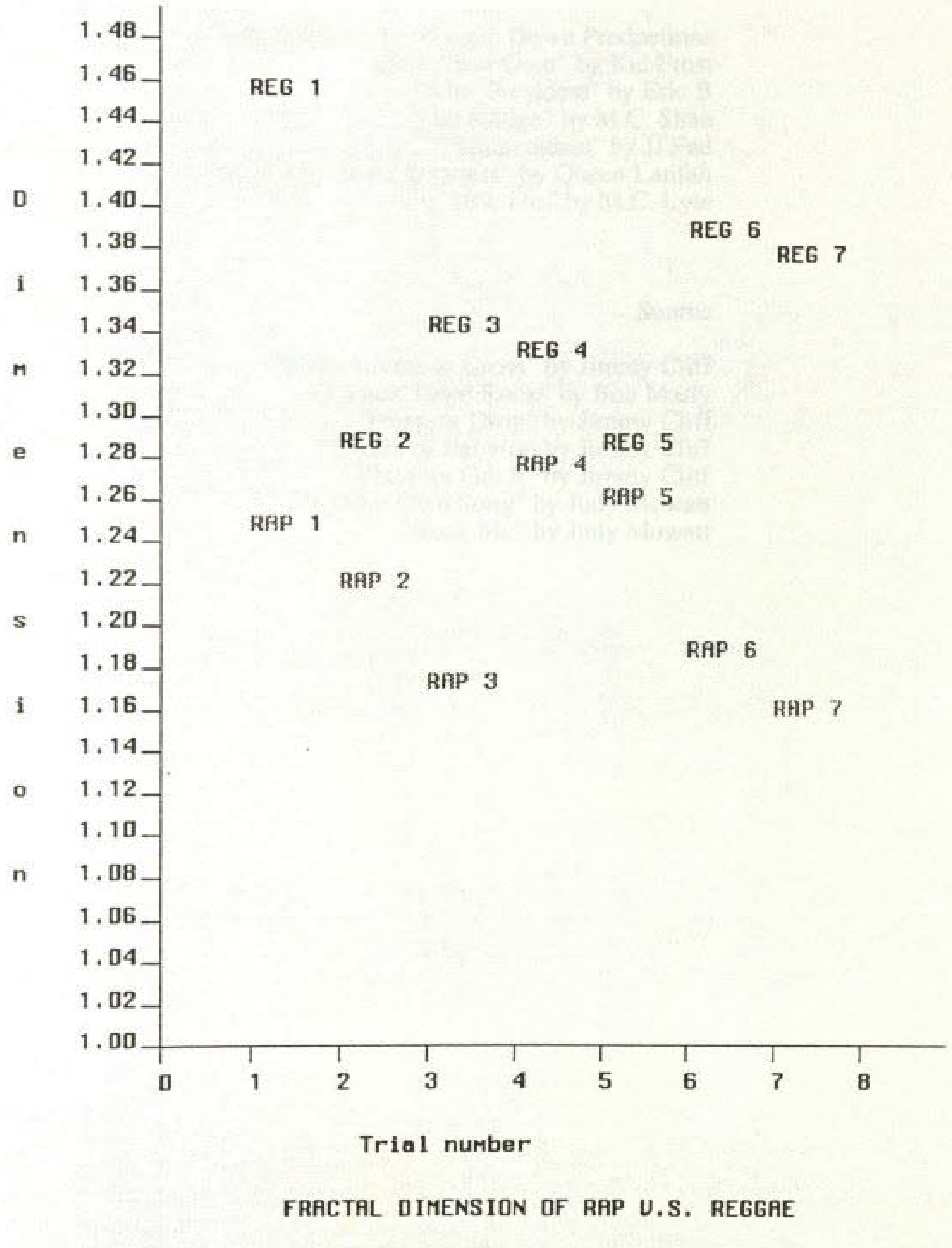


Figure 4.31: Sources for acoustic samples in set 2

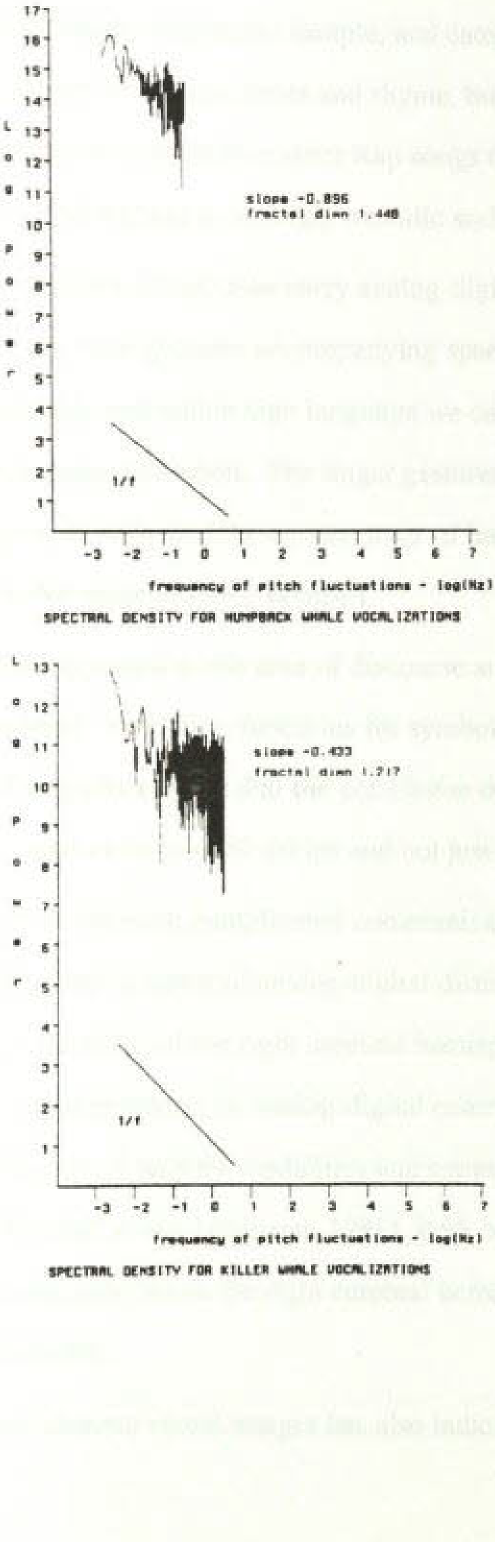
Rap

Fractal Dimension	Source
1.246	"Why is that?" by Boogie Down Productions
1.219	"Hold Your Own" by Kid Frost
1.170	"Eric B for President" by Eric B
1.274	"The Bridge" by M.C. Shan
1.259	"Supersonic" by JJ Fad
1.186	"Queen of Royal Badness" by Queen Latifah
1.158	"10% Dis" by M.C. Lyte

Reggae

Fractal Dimension	Source
1.454	"Many Rivers to Cross" by Jimmy Cliff
1.286	"Trench Town Rock" by Bob Marly
1.341	"Pressure Drop" by Jimmy Cliff
1.329	"Rivers of Babylon by Jimmy Cliff
1.285	"You Can Get It" by Jimmy Cliff
1.386	"Sing Our Own Song" by Judy Mowatt
1.374	"Rock Me" by Judy Mowatt

Figure 4.32: Power spectra of cetacean vocalizations



4.12 Discussion of Results

In addition to unknown parameters, variation within categories may be due to lack of control over word rate, length of acoustic sample, and category definition. The poetry was restricted to those poems with clear meter and rhyme, but finer distinctions could be made. Similarly, an attempt was made to restrict Rap songs to those in the non-melodic style (e.g. no hip-house), and Reggae to strongly melodic styles.

Other discourse modalities should also carry analog-digital distinctions. For example, we can expect ordinary limb gestures accompanying speech to be more analog than the gestures of sign language, and within sign language we can expect both paralinguistic (emphatic) and linguistic communication. The finger gestures for musical keyboards versus word processing keyboards, and the written trace of handwriting versus typeface are also good candidates for representation contrast.

An entirely different approach to the area of discourse analysis has been initiated by Li (1989), who has measured correlation functions for symbol distribution rather than physical parameters. His results suggest that the correlation decrease due to non-unique mapping discussed here applies to symbol strings and not just physical measures.

While discourse offers the most complicated communication, other biobehavioral processes can also be analyzed in terms of analog-digital distinctions. For example, the difference between specializations of the right cerebral hemisphere and left cerebral hemisphere has often been characterized as an analog-digital contrast, and the lateralization of signals from a wide variety of sensory modalities and communication systems has supported this distinction (Bradshaw and Nettleton, 1981). Both behavioral and neurological evidence suggests that cetaceans utilize the right cerebral hemisphere for their analog communications (Eglash 1984).

The lateralization of abstract visual images has also indicated consistent relations

with fractal dimension. While the familiar Euclidian shapes attached to specific names (circle, rectangle, etc.) lateralized to the digital left hemisphere, more random shapes are lateralized to the analog right hemisphere. But the right hemisphere lateralization decreases as shapes become "too random" (Young, 1983). In other words, the right hemisphere lateralization seems to covary with approximation to 1/F spectral distribution for unfamiliar visual images.

Cerebral lateralization also offers the opportunity to see how these different representations operate systemically. For example, observations of neural signals in the visual cortex of the cat (Lestienne *et al,* 1990) indicate that digital coding increases gradually with early development. This suggests a parallel development with the change from analog to digital representation in social communication, and right hemisphere to left hemisphere cerebral lateralization, as observed in a variety of non-human animals (Deuenburg, 1981).

Social communication in humans is a much more complex issue; in the matrix of culture the contrast of analog and digital has historically been used to denigrate various social groups. Derrida (1974) has described some of the history of racism pivoting on supposed difference between languages, illustrated through Rousseau's romanticism of Chinese as a language which is more musical, closer to nature (the "natural cries of animals"), and has yet to have its "accentuation" completely corrupted by the artifice of "articulation" -- in other words, more analog. But since Derrida, like Rousseau, fails to see analog as representation, he feels he must counter this portrait of the linguistic Noble Savage through an explication of the universality of physically arbitrary coding in all speech - in other words, all languages (even ancestral proto-languages) are fundamentally digital.*

*This is not meant to suggest any racism on the part of Voss and Clark; their framework was about coding differences, not the Rousseau's category of the uncoded.

Certainly it would be possible to use the findings in this experiment to support Derrida's admirable efforts: Fractal dimension in Chinese pitch fluctuations indicate the same variation in analog/digital position as those of English, and are quite different from the analog communications of whales. But if we grant that analog and digital have the same ability to represent knowledge, then the reason for insisting on the universality of digital primacy in language becomes less clear. In addition, pitch fluctuation in the particular spectral frequency band and periodicity range examined is simply one of many communication channels: should all of the axes of variation be summed into a single measure, as is usually done in chaos theory? If these other channels have a significant presence, then they cannot simply be summed or averaged into a single analog/digital position; it is in their interactions - the contradictions in irony for instance - that the interpretive depth of communication, which postmodernists such as Derrida have so effectively insisted on, will be found.

The "primitive" is said to be concrete, physical, and more concerned with emotion and body than with arbitrary symbol systems. The "oriental" is stereotyped as abstract, arabesque, and more concerned with logic and symbolic systems than emotion. By promoting the sense of analog and digital as representation systems equally capable of conveying any type of information - a claim supported by recent evidence for computational universality in analog systems (Blum *et al,* 1989) - we can contest some of these degradations. But more importantly, we should encourage recognition of the complex multiplicity of communication channels existing in a seemingly unitary waveform. Social discourse is always an intricate network of many different kinds of representation; it cannot be reduced to any one position on the analog-digital continuum.

4.13 Conclusion

The technical purpose of this chapter was to show that the association of recursion

with chaos, and the dichotomy between analog and digital representation, and not merely convenient cultural metaphors appropriated from odd corners of cybernetics. They are fundamental to the mathematical models of nonlinear dynamics, and correspond to empirical phenomena existing at the interface between meaning and material substance. But when I assess this work, and my my goal of doing science in a framework of cultural critique, it seems to fail on several counts. First, its not much in the way of science -- the math is sketchy at best, my empirical sample size is too small, etc.. Mea culpa. Second, it seems that much of my "alternative" approach is politically modernist. Replacing equations with facial expressions might be a radical move for popular access, but the idea was developed in 1973 by Chernoff within a context that includes military applications (see Wang 1978 for details), and such substitutions can be seen as part of the larger move towards analog representation as a part of social control outlined in chapter 3. Those parts of my work that are postmodernist do not rely on humanist or organicist assumptions, and are thus not betrayed by the reversals of the 1970s. But they don't seem inherently political to me either.

What does seem successful to me is this work as an attempt to use the cultural components of science positively, as tools for understanding, rather than as obstructions on the road to truth. Perhaps the best example of this is the Reggae/Rap comparison. It is not that Science has cleverly revealed the unconscious use of different types of representation, but that music of the African diaspora has been able to express a complex conflict of cultural identity by consciously choosing different representation types. In other words, it is not so much an analysis of a culture as it is a method for explicating how that culture is doing its own analysis.

There is a second feature of the Rap/Reggae contrast that suggests a culturally embedded scientific perspective. For Reggae, a tradition similar to that of Negritude ideals is claimed; African culture is seen as one of physicality. Recall, from chapter 1,

the origins of the golem in the cultures of North Africa, and the association of the golem with Wiener's analog systems. Could there be an historical development from the traditions of sculpture and physical dynamics in African thought, via Wiener's golem, to the development of analog representation in cybernetics?

The attraction here is, again, a way of turning tables on the notion of science analyzing culture, and seeing that very analysis as deriving in the culture it purports to analyze. I suspect, however, that this history is too broad to make any strong conclusions. The analog/digital dichotomy is so pervasive throughout societies and intellectual pursuits that it can be linked everywhere. But where analog systems are recursive, they are not so ambiguous. In the following chapter, we look at an analysis of recursive physical structures in African culture, and will use this mathematically specific form to follow its role in the historical development of "mainstream" science.

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Chapter 5: The African Geometry of Fractals

5.1 Introduction

The last chapter was an attempt, albeit a small one, to do a little science the way I'd like to see it done -- science which takes advantage of both the generation of objective facts, and the experience of ineluctable subjectivity. By intertwining aims toward the universal and the local, I hope we can open the way towards more accessible practices, ones which can hold scientific processes more accountable to their social facets. In this final chapter I'll attempt the same intertwining from the opposite direction. Here we will examine fractals in African material culture, with an eye toward holding these social processes more accountable to their scientific facets.

By now the reader should find it easy to predict how my analysis of these African fractals will proceed. They will be divided into two components: a recursive information flow, and their analog representation medium. We will then look at how certain Euro-american practices treat these components as utopic categories -- the illusion that analog representation (e.g. images rather than symbols) is more natural or more concrete, and the illusion that recursive information (e.g. self-control rather than imposed control) is inherently more liberating. But it is not enough simply to point out the flaws in the analyses of others. Understanding fractals in Africa requires an account of Africans themselves as practicioners of chaos.

This requirement brings up two problems. First, any cultural account is plagued by the dangers of totalizing descriptions. In the attempt to create a cohesive analysis, we create a homogeneous one, an essentialism that erases all the diversity and dynamics which comprise the actual depths of culture (c.f. Mudimbe (1988) for a detailed analysis on how the category of "African philosophy" has been invented in the play between "the

beautiful myths of the 'savage mind' and the African ideological strategies of otherness"). Essentializing would be particularly dangerous if it were claimed that Africa's essence is chaos. Second, any interpretation of fractal geometry in African culture is already over-determined by two varieties of racism. In the primitivist interpretation, Africans would have a fractal geometry because fractals are "the geometry of nature" -- and as primitives they are more natural. In the orientalist interpretation, African fractals would signify minds which are ethereal and abstract, unconsciously channeling Platonic forms from higher realms.

In response to the latter problem, we will examine these fractals in terms of their attributes as conscious designs -- as structures which require work, careful thought, and the investment of social meaning. This will be aided by the "ethnomathematics" approach recently developed by Ascher, Gerdes, Washburn, and others (see Crowe 1987 for a review). The ethnomathematics study will in turn lead us to some possible influences of these African concepts of recursion on "mainstream" science and mathematics (that is, the kind of history told in the introduction to science textbooks). In response to the former problem, we can begin by saying that both chaos and order coexist in most aspects of every society. What is claimed about Africa here is the indigenous invention of one very specific kind of chaos, formalized in both physical structures and symbolic systems. In a sense, I am saying that this formalized chaos is an intellectual resource that Europe and America have extracted from Africa. But in contradiction to essentialist assumptions, we will see that the social meanings attached to these forms vary tremendously between (and even within) different African cultures.

This emphasis on differences rather than unities is one way of avoiding an essentialist description of Africa. But fragmentation can also have an essentializing function. For example, primitivist portraits of Africa have often depended on splitting Egypt away as a European fragment. In this chapter I will be working with the notion of Afrosemitic

culture, a diasporic permeation of boundaries that disrupts static totalizations of both Africa and Europe.* Afrosemitic culture itself is not in danger of becoming an essentialist unity; if anything it is in danger of literally blowing apart at the seams and taking the rest of the world with it.

In gender studies male is an unmarked category, a generic or norm that needs no comment. Similarly, white is an unmarked ethnic category; hence "White ethnicity" seems like an oxymoron. Gay men are still male, but have a marked maleness; my own Jewish identity is similarly one of marked Whiteness. But this marking has made Jews very handy for use as intermediaries between White and Black. Societies which mediate the interactions between two cultures have often been referred to as "culture brokers," but the retail metaphor is not particularly attractive for Jews. I prefer to think about this in terms of biological cell membranes. Cell membranes actively select certain substances for passage, and often in one direction only. When indigenous writing systems or other examples of formal order have been found in Africa, Europeans have often proposed the "Hamitic" theory of origin, that these people are not really African but are European derived semites. Conversely, when Europe seeks to purify itself of disorder, Jews become representatives of the non-white Other. In some ways this essay is the cultural equivalent of reverse osmosis, a pathological cell condition in which the membrane allows substances to travel in the wrong direction.

5.2) Fractal Geometry in Traditional African Architecture

I want to begin with some examples of fractals in African architecture. This is not

*The history of European denial for this mixture of Jewish, African, and Arabic cultures was recently explored by Bernal (1987), and its origins in Egypt are discussed in St Clair (1987). An early exploration of this theme in the American Jewish context can be found in Mezzrow and Wolfe (1946). Some of the political possibilities for the Afrosemitic *tsimmes* have recently been addressed in talks by Paul Gilroy (1992), and in the rap song "Why is That?" by Boogie Down Productions on *Ghetto Music: the blueprint of hip-hop* (Jive 1187-4-J).

intended to be a random or representative sample of all African settlements; I have simply picked what I consider to be good examples of those architectures which exhibit recursive scaling structures, and presented these with a discussion of some simple relations between the recursive physical structure and recursion in social processes. Next we will consider a quantitative measure of the fractal dimension for these patterns, and finally we will examine the problems of humanist and organicist interpretations.

That fractals may be a common form for African architecture is hinted at in Zaslavesky (1973), who notes that "[a] remarkable feature of African architecture is the over-all consistency in form. ...Round houses are generally arranged in round or elliptical compounds, rectangular houses in oblong compounds." In the following cases the only commonality is that they are all self-similar, not that they are similar to each other. This is not a simple unity.

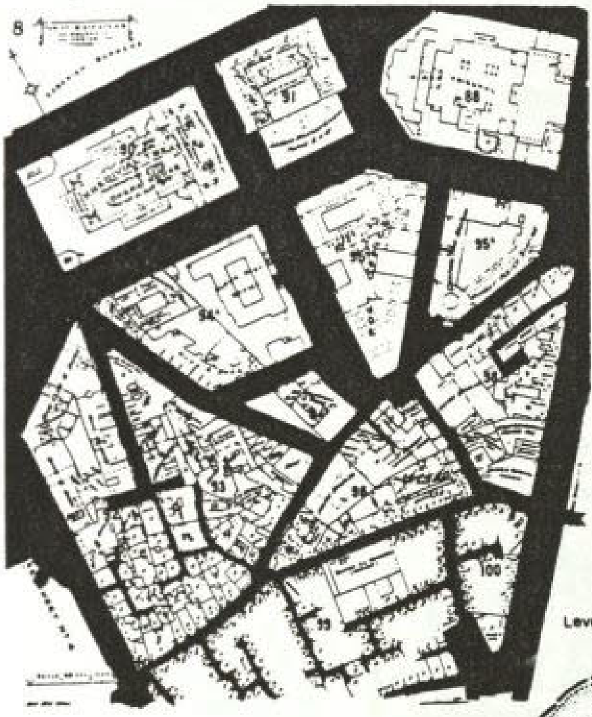
Readers familiar with branching fractals will appreciate the scaling in figure 5.1a, a map of the streets in Cairo, 1898. Delaval (1974) has described the morphogenesis of Saharan cities; the pattern has some isomorphisms to fractal generation by iterated function systems. The first 'pre-image' consists of a mosque connected by wide avenue to the market place, and successive iterations of construction require successive contractions of this form (figure 5.1b).

In figure 5.2a an aerial photo of Logone-Birni in Cameroon shows recursive applications of rectangular enclosures, a form which allows for dynamic response to changes in the productive infrastructure. Figure 5.2b shows a map of a Bamileke homestead in Cameroon; note that the head household has a circular ring of pillars setting it off from the other square structures. Such breaks from the overall recursive form are commonly used to signify a social distinction.

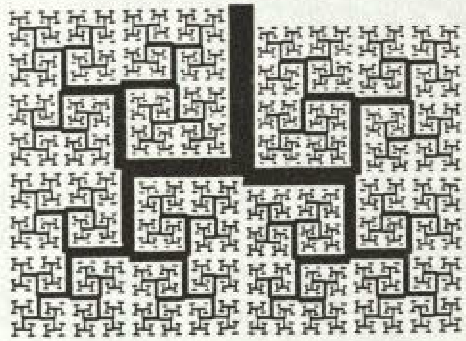
The aerial photo in figure 5.3 shows an Ila village in southern Zambia. The large

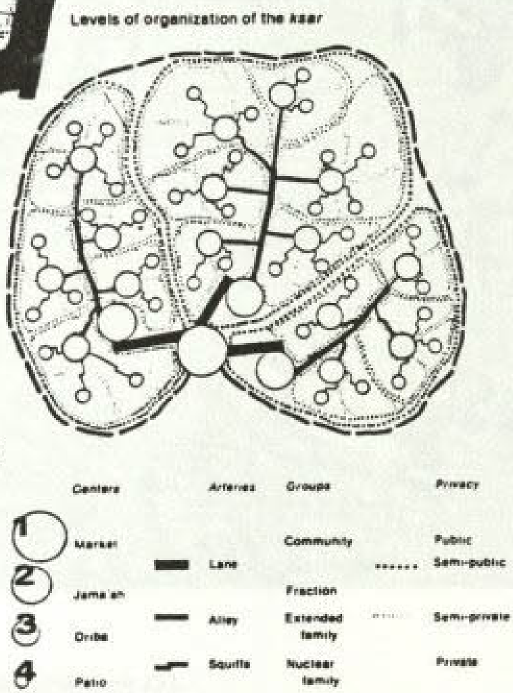
Figure 5.1: Branching fractals in Saharan cities

Figure 5.1a: map of streets of Cairo, 1898



b: branching fractal





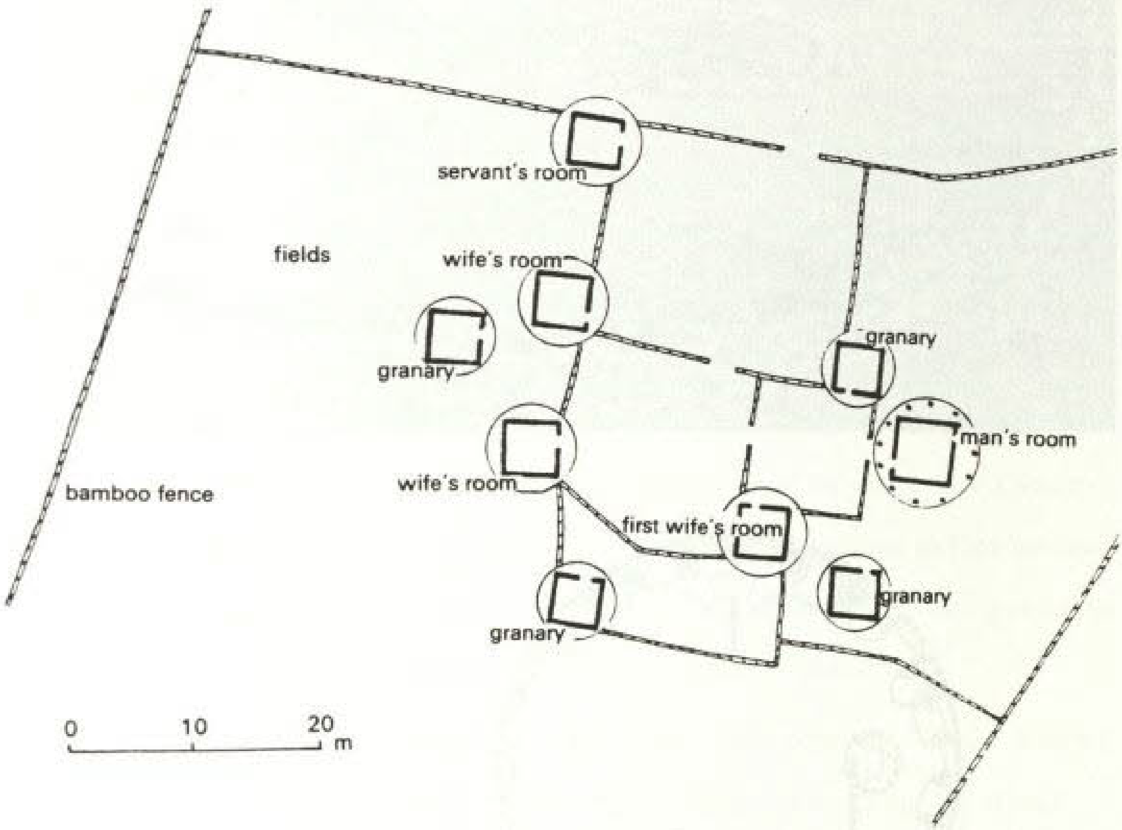
c: morphogenesis of Saharan cities

Sources: a) Chas Goode Civil Engr. b) Mandelbrot 1982. c) Delval 1974.

Figure 5.2a: Longone-Birni in Cameroon

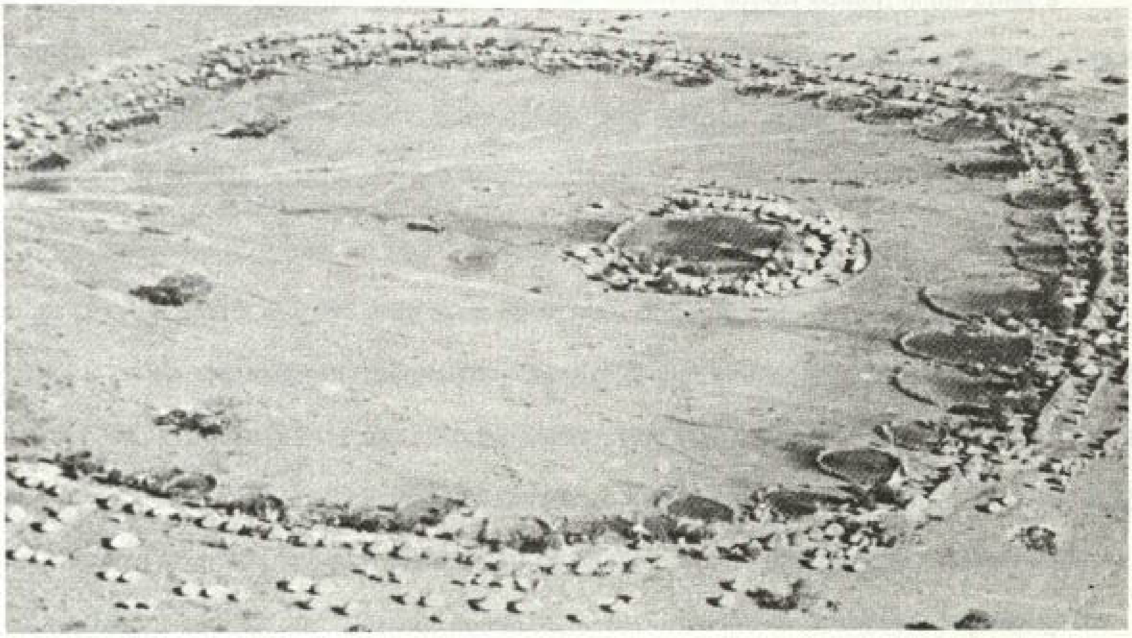
From B. Rudofsky (1964) pg 131.

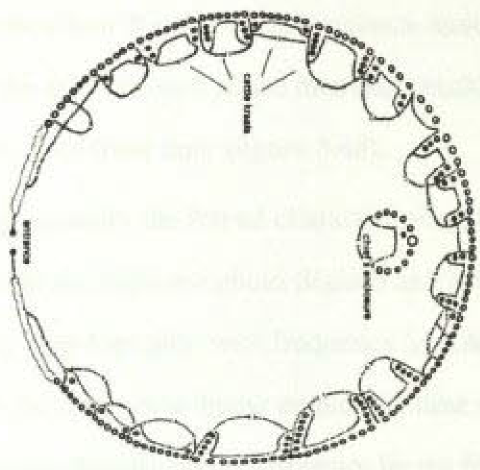
Figure 5.2b: Bamileke homestead in Cameroon



From Denyer (1987) pg 77.

Figure 5.3: Ila settlement in southern Zambia





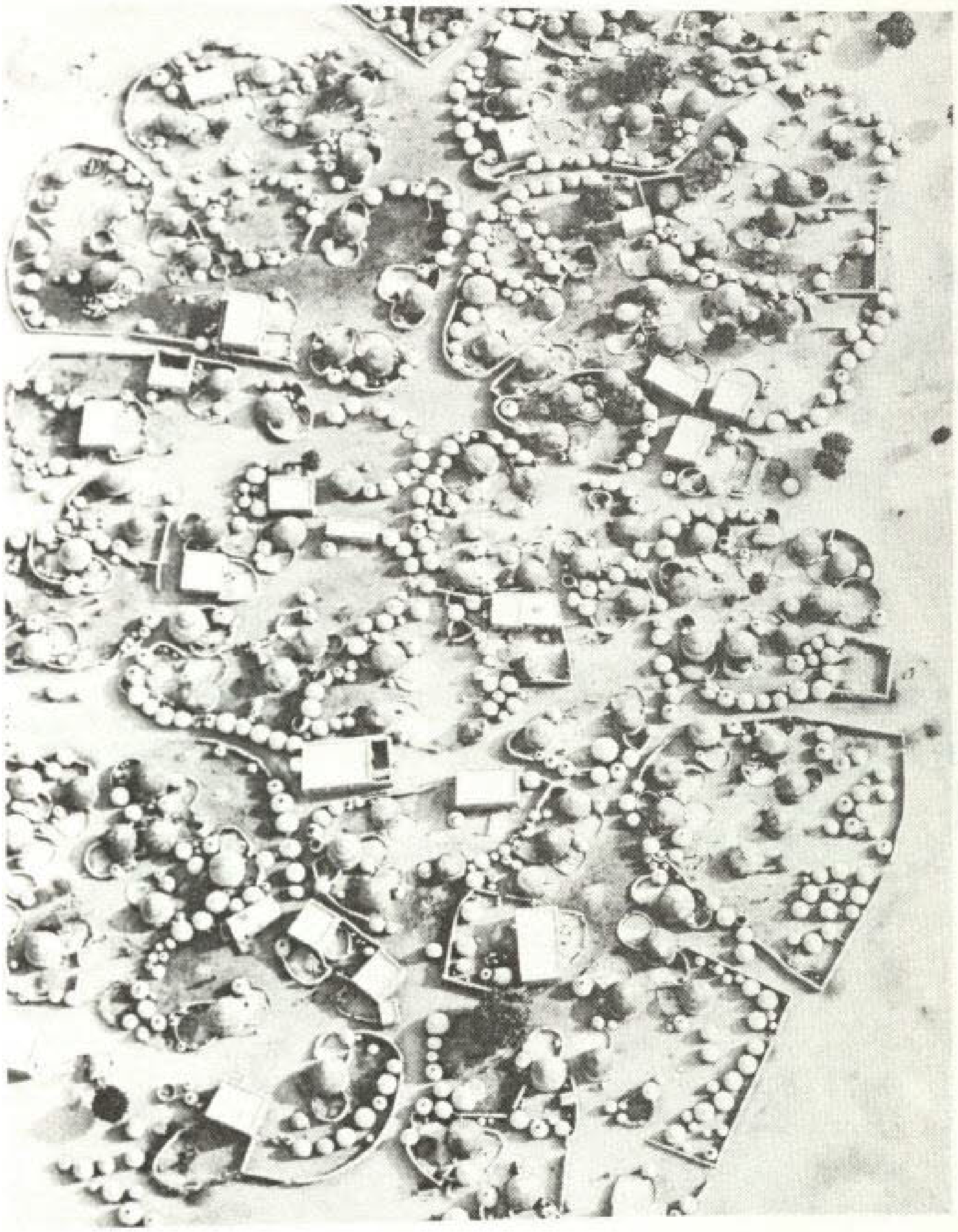
From Denyer (1987), pg 146, 147.

outer ring is made up of the smaller rings of family kraals, each of these smaller circles uses circular houses, and inside each house are circular graineries. The inner ring, set off center, is the chief's family and kraal. Within this ring, set off center, is the chief's house. The recursion stops here however, since the chief's house is square (again using a break in recursion to set a social distinction). The three off-center forms suggest a syllogism: chief:chief's family::chief's family:village.

Figure 5.4a provides an aerial view of the Songhai village of Labbezanga in Mali. Here circular structures not only exist on several scales but are themselves arranged in circular swirls reminiscent of Julia sets or other fractal images (figure 5.4b). Bourdier and Trinh (1985) describe a similar circular architecture in Burkina-Faso, where the recursion continues down to pots stacked in the circular fireplace (figure 5.4c). They cite an analog relationship between social meaning and physical structure in terms of continuous physical changes along an "intimacy gradient," and also note the decrease in "irregularity" of architecture with increased centralization in labor organization. In yet another circular scaling architecture, Blier (1987) describes how Batammaliba architects include the construction of small earthen mounds for the spirit of each house member, resulting in a tiny replication of the larger circle of circles at its front door (figure 5.4d).

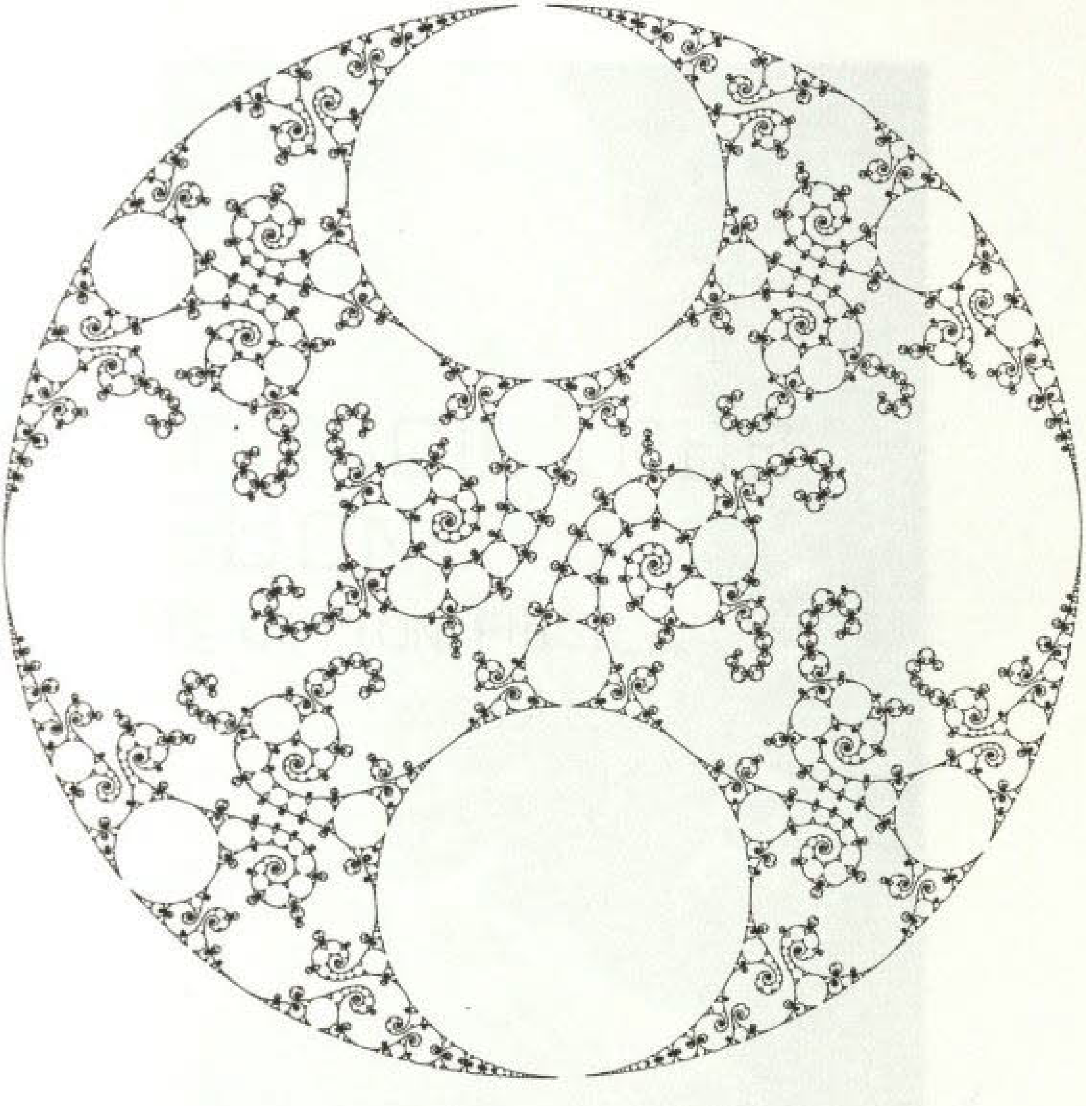
Peter Broadwell and I attempted to quantify the fractal characteristic of the Songhai village by applying a Fourier transform to the digitized photo (Eglash and Broadwell 1989). This produced a spectral density (log-log) plot with frequency in polar coordinates on the horizontal plane. Figure 5.5a shows how linear patterns in time (in this case a heart beat) are converted into a frequency domain power spectrum by the Fourier transform. Purely random noise would produce a flat spectrum with dimension 1. A purely periodic signal would have dimension 2. Figure 5.5b shows the negatively sloped frequency spectrum ("1/F noise") characteristic of fractal time series (the slope is in linear proportion to the fractal dimension; see Voss 1988 for details). At the bottom of

Figure 5.4a: Songhai settlement of Labbezanga in Mali



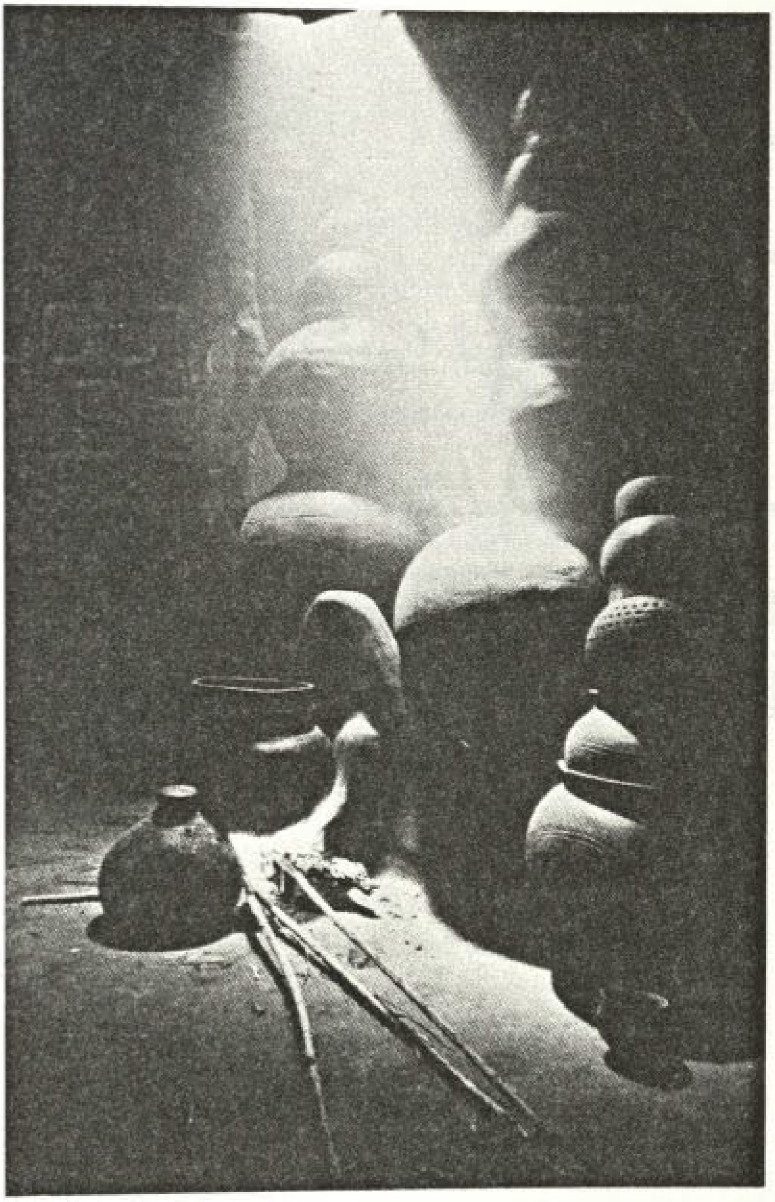
From Duly (1979) pg 19.

Figure 5.4b: Circular fractal



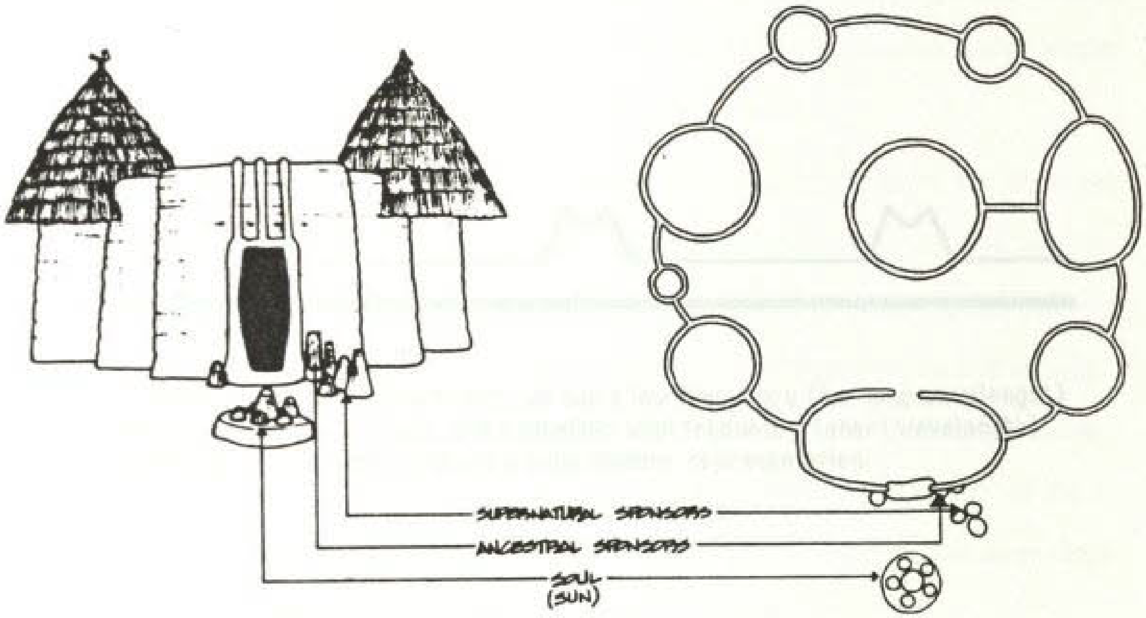
From Mandelbrot (1982) pg 178.

Figure 5.4c: Pots stacked in fireplace in Burkina-Faso



From Boudier and Trinh (1985) pg 184.

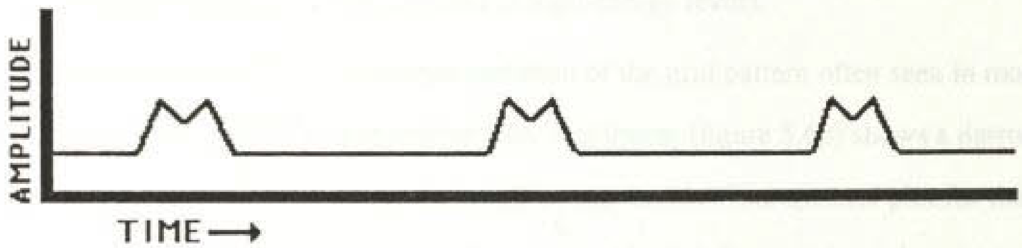
Figure 5.4d: Spirit doubles in Batammaliba architecture



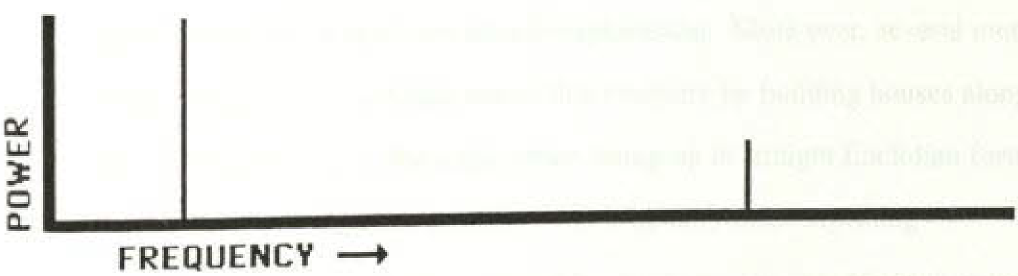
From Blier 1987, pg 131.

Figure 5.5 a: The Fourier Transform

A frequency domain representation



In the time series of a heart beat, we see a low frequency (i.e. long wavelength) interval between each beat, and a smaller high frequency (short wavelength) "lub-dub" within beats. This is a time domain representation.



In the frequency domain representation, we would see the heart beat as cycles with different power levels. Most of the power is from the low frequency beats, but there is also some power from the high frequency pulses within beats.

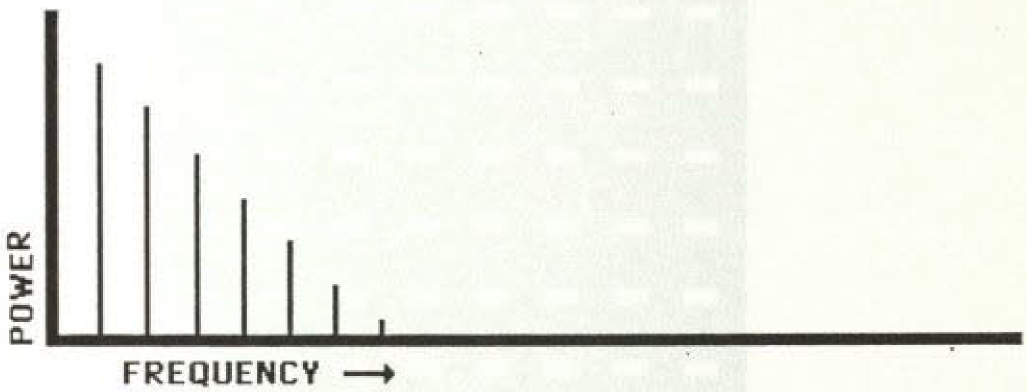
figure 5.5b we see how this power spectrum can be swept in a circle to produce a two-dimensional spectrum in polar coordinates. Here fractal spatial structures will produce a cone shape, again with the slope in a linear proportion to the fractal dimension. The following plots were produced by taking horizontal slices through the spectra at selected energy (power) levels; for fractal images we expect to see increasing brightness towards the outer edge (indicating high frequencies) at low energy levels, and increasing brightness towards the center (low frequencies) at high energy levels.

Figure 5.6a shows a stylized representation of the grid pattern often seen in modern Euro-american housing. The spectral plot for this image (figure 5.6b) shows a narrow-band clustering of periodic frequencies at all energy levels. The spectral plot for the fractal image in figure 5.4b shows a tendency towards high frequencies at low energy levels (figure 5.7a) and low frequencies at high energy levels (figure 5.7b), with some distortion of the cone shape due to the axes of symmetry. For the aerial photo of the Songhai village a cleaner cone shape was apparent (5.8a, 5.8b), with a more even slope (we guestimate around -1, giving a fractal dimension of about 2.5).

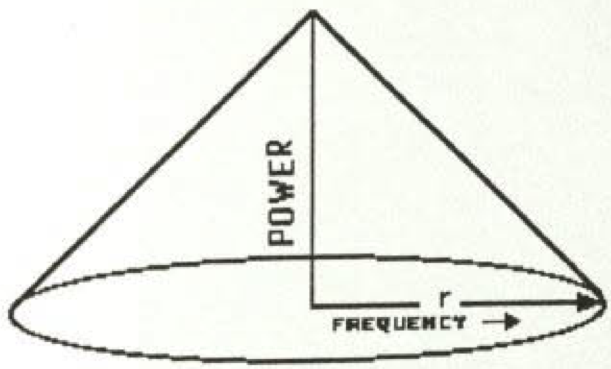
Stoller (1984) recently described a Songhai town in which a caste system ensured that the best land was voluntarily given over to the highest caste members. The town was self-organized, but this was a form of self-exploitation. More over, several members of the community had decided to break out of this structure by building houses along the new highway. Thus liberation in this case meant lining up in straight Euclidian formation. This was actually the opposite relation I had originally been expecting.

My work in applications to African material culture started with Caplan (1979) on women's autonomy in Tanzania. She described how the flexibility of housing allowed women to create new homes if they wanted a divorce, or to extend old homes if they wanted to shift the family structure. When socialism brought the new modernization programs, this autonomy was threatened by the "improved" housing design, which

Figure 5.5 b: Fractals in the Frequency Domain

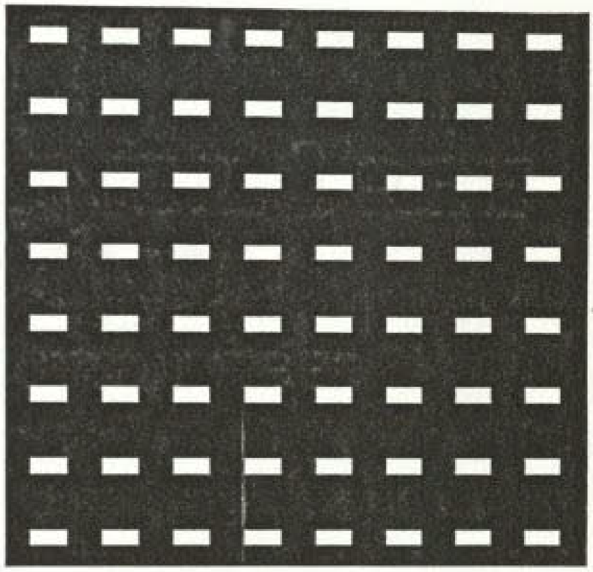


Fractal waveforms are characterized by a decrease in power as we look at increasingly higher frequencies. In general we can say that power in fractal waveforms varies as the inverse of frequency, hence "1/F noise."

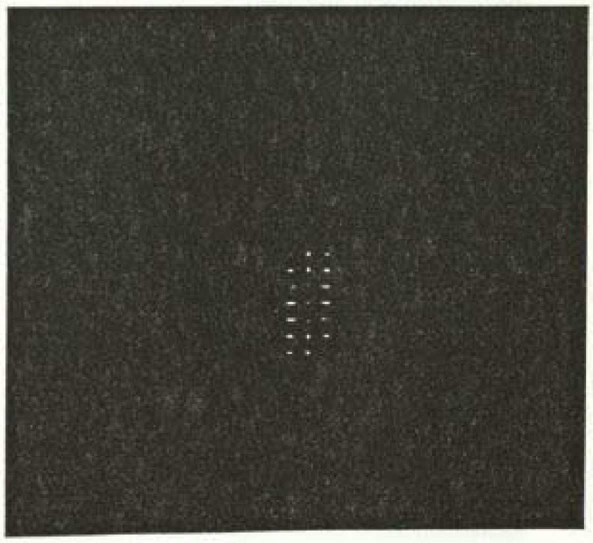


Just as a one dimensional time series waveform can show fractal scaling distributions, a two-dimensional image can also be analyzed in terms of its frequency characteristics. Here we display frequency in polar coordinates, so a wider circle = higher frequencies. For a fractal distribution, the radius r should be smaller as we go up in power.

Figure 5.6: Grid pattern typical of Euro-American architecture

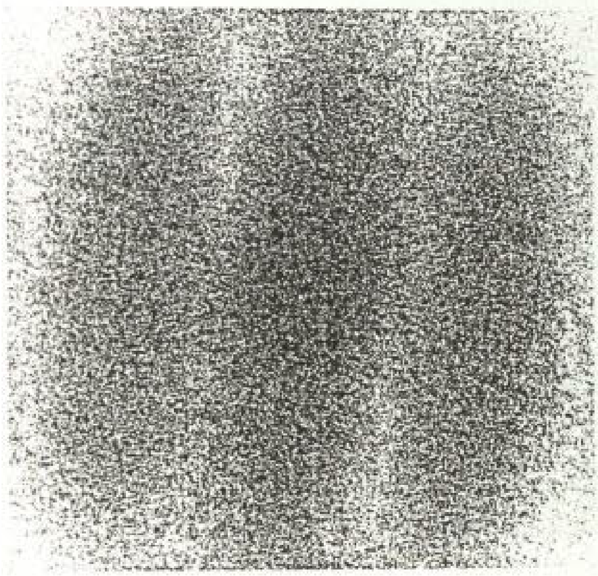


(a). Spatial grid pattern

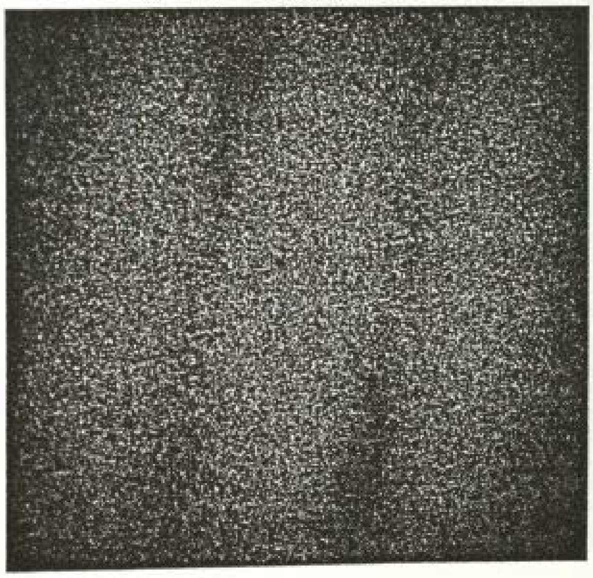


(b). Spectral plot for grid pattern

Figure 5.7: Spectral plots for circular fractal (fig 5.4b)

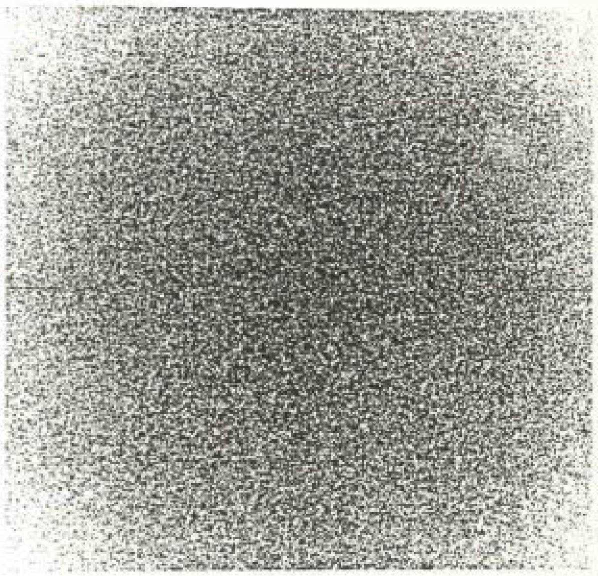


(a). Spectrum of circular fractal shows high frequencies at low power levels.

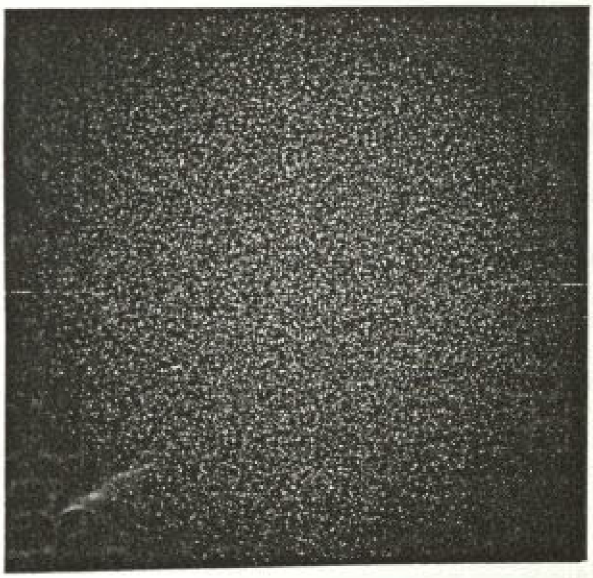


(b). Spectrum of circular fractal shows low frequencies at high energy levels.

Figure 5.8: Spectral plots for Songhai settlement (fig 5.4a)



(a). Spectrum of Songhai photo shows high frequencies at low power levels.



(b). Spectrum of Songhai photo shows low frequencies at high energy levels.

sometimes resembled concrete army barracks. It occurred to me that aerial photos might show the difference between these architectural designs as fractal v.s. euclidian; that the self-organized community would have a self-similar geometry.

Pat Caplan generously provided me with aerial photos of the area she worked in, and the indigenous housing did indeed appear to be less Euclidian, although the scale of the photo prevented a conclusive analysis. But the contradiction from Stoller's work nicely illustrates Foucault's warning against simplistic humanist formulas: Self-determination is not necessarily liberating, it can serve to support social control rather than resist it.

In addition to disrupting humanist interpretations, I also would like to prevent organicist or romanticist use of my work. In Dogon architecture we can see a Derridian approach to this problem. For the Dogon the human shape is not only our biological form, but maps meaning at all levels: "The fact that the universe is projected in the same manner on a series of different scales --the cosmos, the village, the house, the individual -- provides a profoundly unifying element in Dogon life" (Duly 1979). This information is given an analog representation for many of the Dogon houses, which have a physical outline suggesting head, arms and torso. But the representation of the human form at the level of the village is through physically arbitrary symbols: the smithy stands for the head, the menstrual lodges as hands, etc.. The meaning is recursive -- humans people houses, houses people villages, villages people the cosmos, the cosmos is a person -- but the digital representation prevents physical self-similarity.

The advantage with this approach is that it counters totalizing portraits of Africa as essentially analog (see Juma 1989 for a potent version of this strategy through the digital aspects of plant genetics). All cultures have both analog and digital systems throughout most of their social processes. But Derrida's theory assumes that only the existence of digital representation is really capable of preventing primitivism. We can also counter the

organicist claim of more "natural" societies by seeing analog systems as artificial. The following section will examine the role of a supposed natural chaos of Africa under colonial control.

5.3) Chaos and Colonialism

The "naturalness" of African architectural chaos has been a discursive tool for many colonial enterprises. But the conceptual foundations for this occurred long before the colonization of Africa had become effective, as evidenced in this passage from Rene Descartes (1673).

> [T]here is less perfection in works made of several pieces and in works made by the hands of several masters than in those works on which but one master has worked. Thus one sees that buildings undertaken and completed by a single architect are commonly more beautiful and better ordered than those that several architects have tried to patch up.... Thus I imagined that people who, having once been half savages and having been civilized only gradually, have made their laws only to the extent that the inconvenience caused by crimes and quarrels forced them to do so, would not be as well ordered as those who, from the very beginning of their coming together, have followed the fundamental precepts of some prudent legislator (pg 12).

For Descartes self-organized is a synonym for imperfection of both material and social structure. Lack of complete Euclidian regularity means randomness: for "streets crooked and uneven, one will say that it is chance more than the will of some men using their reason that has arranged them thus" (pg 12). The lack of Cartesian coordinates in many African settlements would thus evidence their need for the guidance of colonial reason.

As Hull (1976) notes, huge centers of urban life in Africa were indeed disregarded as "unstructured bush communities" on just these principles. While Timbuktu was granted city-hood due to its grid pattern of streets, the Yoruba* cities of equal population size and economic, technical, and cultural complexity have been regarded as giant vil-

*Recursive architectural structure is linguistically indicated by the Yoruba term for homestead: *ot ka ot*, or "house within the house."

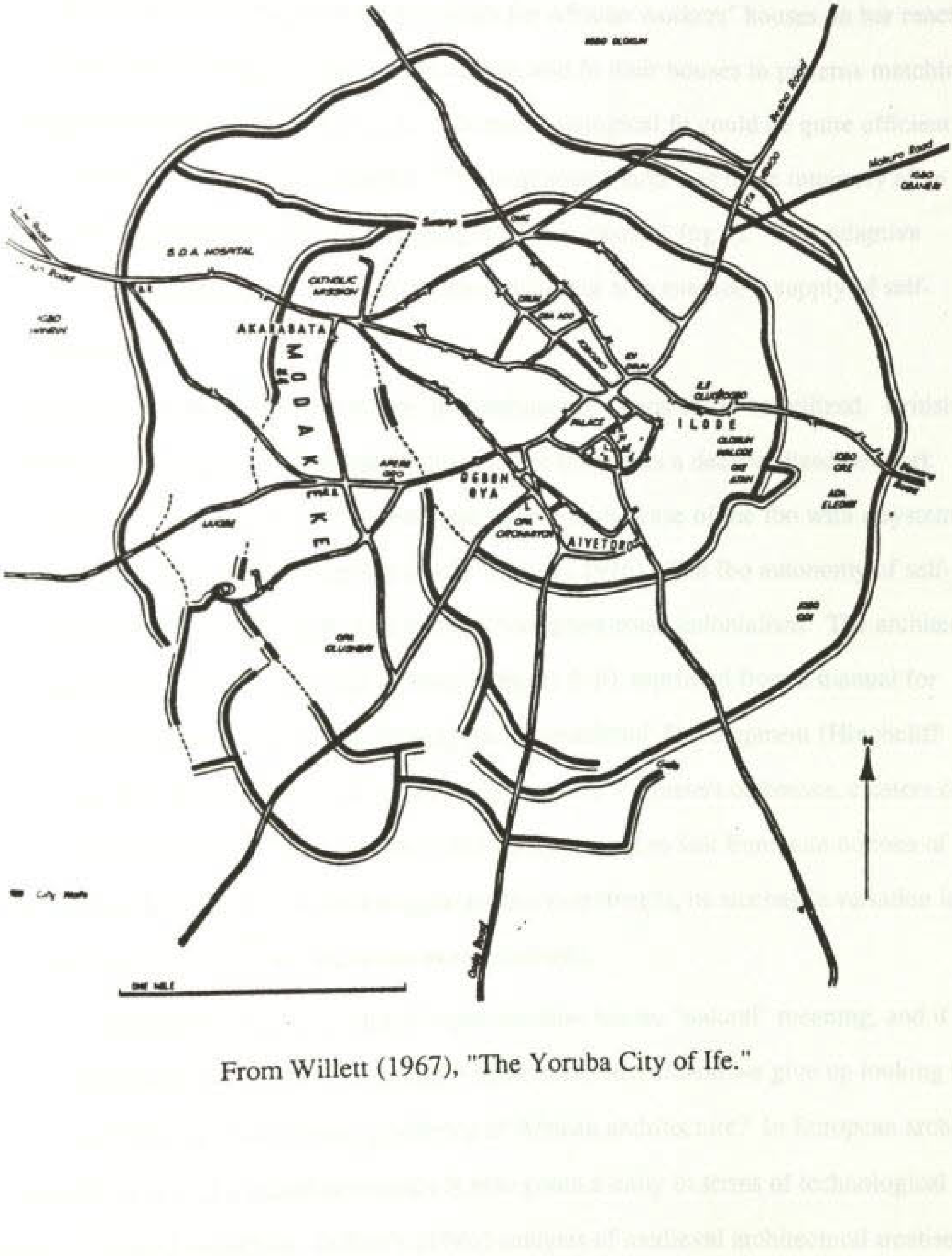
lages due to their lack of Cartesian regularity (figure 5.9). This debate over the urban status of non-euclidian settlements continues in the post-colonial era (see Schwab 1965, Lloyd 1973).

Even Cartesian linearity in the construction of walls presents a problem for colonial justification through primitivism. In 1871 the German geologist Carl Mauch "discovered" the ruins of Great Zimbabwe. Stunned by the evidence of precise stone cutting on a massive scale, he proposed that the buildings were not of African design, but were instead due to the Queen of Sheba's visit to Solomon (Connah 1987). The Rhodesian government used this explanation as a part of its propaganda against Black rule (McIntosh et al, 1989). Actually they had much less to fear in the truth: the stone was not cut, but *naturally* broke into linear sheets (after heating) due to its geologic properties. Moreover, most of the outside of the walls were originally covered with smooth clay, creating a non-linear set of scaling shapes (which Connah refers to as "random curved forms"). This is not to diminish the remarkable technological skill of the construction, but to point out that one culture's sign for artificial can be another's sign for natural. Order versus chaos as a symbol of artificial v.s. natural has no basis outside of a particular cultural construction.

During the development of colonial cities, the chaos of African architecture was used as both symbol and symptom of European fears over social chaos. Pennant (1983) provides an example of this concern about proper settlement geometry in his examination of colonial development in Malawi.

> The language of this 1930s policy discourse is significant. Medical experts wrote of "investigations" showing "unquestionably" and of "abundant proof." ...Lay Europeans showed "concern," "alarm," and "horror." Africans, with their "primitive habits," of "promiscuous defecation" formed a "floating" or "scattered" population in need of "control" and "supervision" in a "properly laid-out village or location."

Figure 5.9: Scaling patterns in Yoruba city structure



From Willett (1967), "The Yoruba City of Ife."

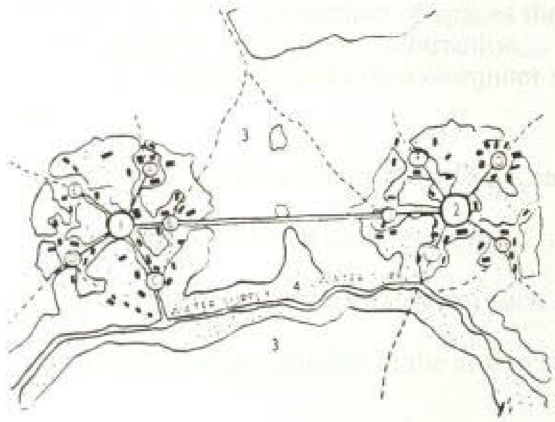
In the above case where primitive mixes with modern, the fractal tradition was a threat. But kept in its natural primitive role, architectural chaos could also be seen as benefit to the colonial enterprise. The novelist Karen Blixen (Isak Dinsen), in *Out of Africa,* described her attempts to lay out grids for African workers' houses on her ranch. They refused to follow these linear instructions, and fit their houses in patterns matching the irregular configuration of the land. That such ecological fit could be quite efficient was not, however, lost on the colonists. "The squatters' land was more intensely alive than the rest of the farm, and was changing with the seasons" (pg 9). This adaptive chaos was not only a part of colonial romanticism, but also ensured a supply of self-supporting workers.

Even in the case of social control, this indigenous chaos could be utilized. British colonial policy, for example, failed in cases where there was a decentralized network rather than a large hierarchy. This was approached in the case of the Ibo with a system of "Indirect Rule" based on "warrent chiefs" (Isichei 1976). The Ibo autonomy of self-control was turned against them; in a sense it was grass-roots colonialism. The architectural equivalent of this system can be seen in figure 5.10, reprinted from a manual for colonial housing designs from the Agency for International Development (Hinchcliff (1946?), pg 31). Here the Ibo fractal settlement pattern -- clusters of houses, clusters of clusters, clusters of clusters of clusters -- is slightly altered to suit European notions of order, while retaining the overall indigenous structure (that is, its stochastic variation is eliminated, but deterministic recursion is maintained).

If the analog characteristic of this representation has no "natural" meaning, and if the recursive information also has unstable semantics, then should we give up looking for any unified meaning in the fractal geometry of African architecture? In European architecture, the variety of cultural semantics is also given a unity in terms of technological and mathematical expertise. In Eco's (1986) analysis of medieval architectural treatises,

Figure 5.10: Colonial use of fractal patterns in Ibo settlements

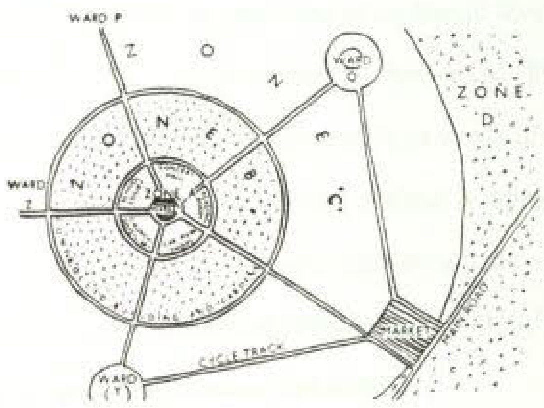
Plan of existing Ibo village showing ward system.



1 & 2. Centres surrounded by house land and gardens.
A.B. etc. Ward centres. 3. Farm land. 4. Swamp land.

From a town-planning viewpoint there is no objection to this maintenance of a horticultural village plan where better suited to the traditions and soil fertility of the locality; indeed, this last factor, from which the wealth of the worker comes, must be a prime consideration in all village planning.

Plan showing proposed method of adapting plan to modern needs.



Zone A—Public land and buildings. Zone B—Controlled buildings and garden plots. Zone C—Free buildings and gardens. Zone D—Farm land.

From Hinchcliff (1947)

he notes that in addition to ideas about cosmology, memory and other philosophic systems,

> You find also an art of combination or generation of spaces through operations of a mathematical sort: multiplication, addition, subtraction.... It is like reading a manual that explains how to generate figures on a computer screen using algorithms (pg 93).

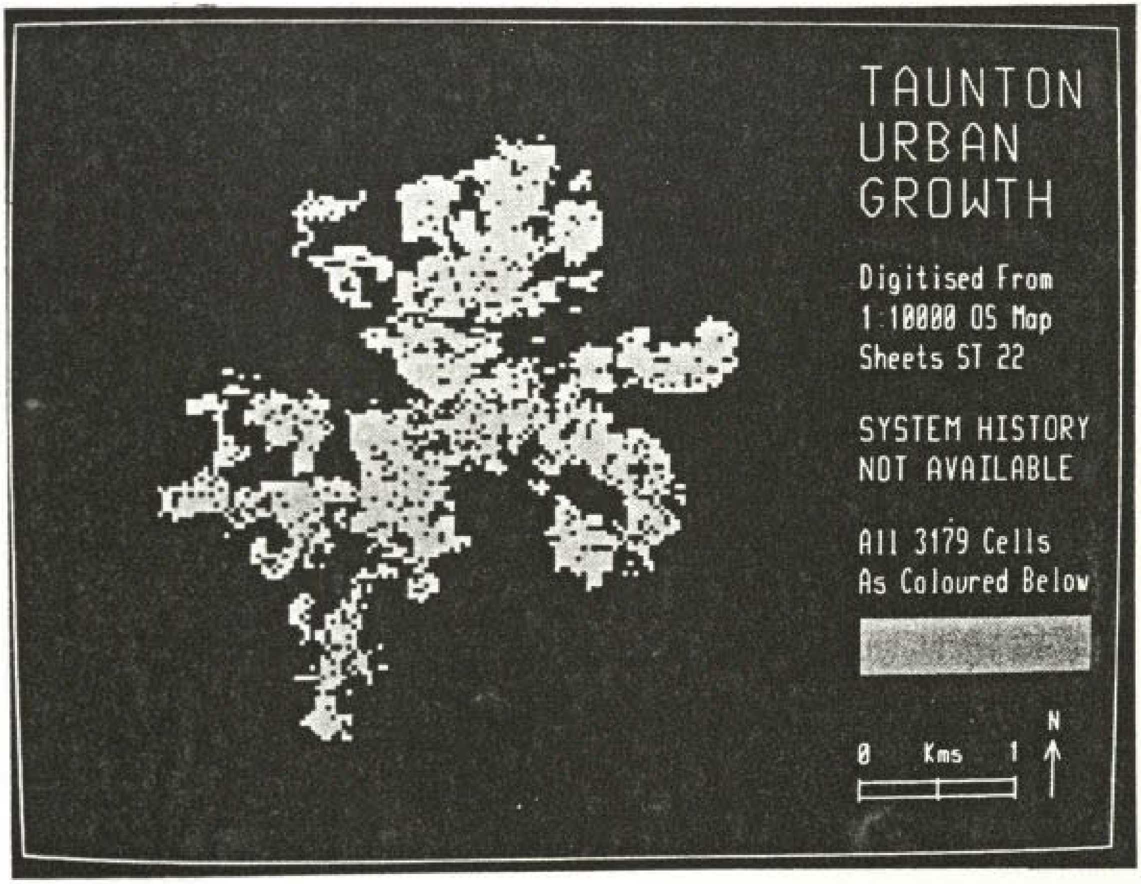
If we can so sensibly credit Europeans with euclidian knowledge based on their architecture, then it follows that African architecture can also be regarded in terms of its mathematical and computational properties. Before we begin such an investigation, it will be useful to survey the fractal/euclidian division in the architecture of a few societies outside of Africa.

5.4) An ethnomathematics survey: are African fractals unique?

Mandelbrot (1982) notes that all architecture can be divided as tending toward either scaling or non-scaling forms. Although he does not cite any architectural structures specifically as fractals, he notes that in some Western architecture, e.g. the Beaux Arts style, certain aesthetic features appear similar to fractal form, and he attributes this to "an effort to imitate Nature and guess its laws." Batty et al (1989) have carried out quantitative models for certain European settlements in terms of fractal dimension; figure 11 shows a typical sample. These fractals are not defined in terms of an explicit geometric algorithm -- a seed shape recursively replacing itself -- but rather as the result of feedback in stochastic forces ("diffusion limited aggregation," a model from physical chemistry) which govern urban population dynamics.

Neither of these two cases resemble the type of fractal design we've just examined in Africa. Mandelbrot's case is based on attempts to imitate nature; the ornament of organic form. Batty's case is Descartes' "chance more than the will of some men using their reason." A better candidate for fractal design in Europe might be some of the Celtic

Figure 5.11: Stochastic chaos model for European city



From Batty et al (1989), pg 1467.

engraving patterns; Briggs and Peat (1989, pg 111) have commented on this relation. An interesting example of purposeful scaling design in Euro-American architecture occurs in Frank Lloyd Wright's use of the Fibonacci sequence; but as we will later see, this mathematics may be of African origin.

Native American architecture seems strikingly non-fractal to me; perhaps even more so than that of Europe in some ways. The best examples are the ancient cities of Mexico, with their universal grids and heliocentric origin points. Octavio Paz expands on a similar observation in *Labrynth of Solitude*. Here the indigenous society "collaborates actively in defending universal order, which is always being threatened by chaos [caos]," while European Romanticism invites "a wound on the compact flesh of the world, and chaos, which is the ancient and, so to speak, *natural* condition of life, can emerge again from this aperture" (pg 26).

> Our devotion to Form, even when empty, can be seen throughout the history of Mexican art from pre-Conquest times to the present. (pg 33)
> [It is in] the ritual complications of our courtesy.... our fondness for closed poetic forms, our love for geometry in the decorative arts and for design and composition in painting, the poverty of our Romantic art.... (pg 32)

A fore-runner of Descartes' quartinary coordinate system appears in an earlier mathematical work, the preface to a popular translation of Euclid by John Dee (1570). One of Dee's optical tools has been identified as an Aztec obsidian mirror (Clulee 1988, pg 207), not suprising considering his interest in the knowledge to be gained by reports from the new world (possibly of additional interest since Dee, like the Aztecs, believed in heliocentricism). A map of Tenochtitlân by Albrecht Dürer clearly shows the quartinary city plan (Pennick 1979, pg 158), and could have been available to Dee at the time. It would be a strange fulfillment of Paz's observation if the European emblem of order had a Native American origin.

Although there are some indigenous American settlements that have scaling, the

scaling features are typically linear rather than non-linear. For example, viewed from the air, the temple of the sun in Teotihuacán can be seen as concentric squares, but the square size changes as a linear function of the radius. Similarly, some of the North American circular tipis were grouped in circles, but all of the illustrations I have seen of these are linear concentric layers rather than the non-linear, self-similar scaling of fractals.*

The Native American use of recursion appears to be much stronger in digital representations, such as the self-contradictory chaos of the trickster in mythological narratives. Nabhan (1983) suggests a potent example in Kokopelli, the fertility figure which several writers have associated with Native American expertise in maintaining genetic diversity in agriculture (previously proof of their chaotic, primitive approach to farming). It might be possible to trace the history of Mexican mathematical research in computational models of biological complexity (see Jimez-Montaño in the previous chapter) in the context of this indigenous tradition.

The South Pacific has often been the subject of complex anthropological claims; and ethnomathematics is no exception. For example, Ascher (1990) has analyzed some of the algorithmic properties of Warlpiri sand drawings. Shore (1982) has analyzed Samoan architecture in terms of the analog/digital dualism. A nice illustration of an Oceanic/European contrast in attitudes towards mathematics and nature can be seen in the film *Trobriand Cricket*. Here an old picture of English cricket players, notching orderly scores into a chaotic tree branch, contrasts with Trobriand players, who keep track of their chaotic scores by tearing sequential leaves off of either side of a perfectly symmetrical palm branch.

Scaling structures also exist in the societies of Oceania. The complex schedualing of water routes in Bali have been the topic of a wide variety of organizational theories.

*That is, even non-linear concentric circles are only self-similar with respect to a single locus (the center point) rather than having a global self-similarity.

Such pseudorandom (possibly chaotic?) sequences could be beneficial in adding aperiodic environmental variation (i.e. 1/F spectra) to crops (see Starr 1990). More specific recursion can be seen in Balinese gamelan, which is based on scaling of percussive cycles-within-cycles, and the architecture of Borobudur, a temple of Indian religious origin in Java.

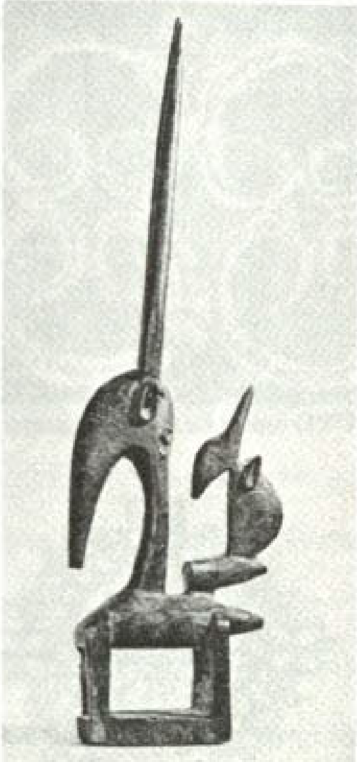
Errington (1992) has suggested that Borobudur is the three-dimensional equivalent of an Indian mandela. More specifically we might note that since the mandela is comprised of iconic symbols, its recursion has a rather digital bias, whereas Borobudor has a much stronger self-similarity in its physical structure, and is thus not only three-dimensional but more analog as well. Such recursive architecture is seen in several temples in India itself -- the Kandarya Mahadeo in Khajuraho is one of the clearest examples -- and is related to recursive concepts in religious cosmology. Murphy (1991) has made this comparison in relation to fractal geometry, and notes that the Dravidian culture associated with these religious followings was disparaged as primitive, and rumored to have historical roots in Africa.

In summary: Fractal structure may be seen in a wide variety of societies, but its use as an explicit recursive design is much more limited. In cases where it does exist, it is possible that some of these have their origin in Africa. Certainly there are cases where fractal designs have arisen independently; my only point here is that the fractal designs of Africa should not be mistaken for a universal or pan-cultural phenomenon. The next section will examine some further examples of fractal design in African material culture.

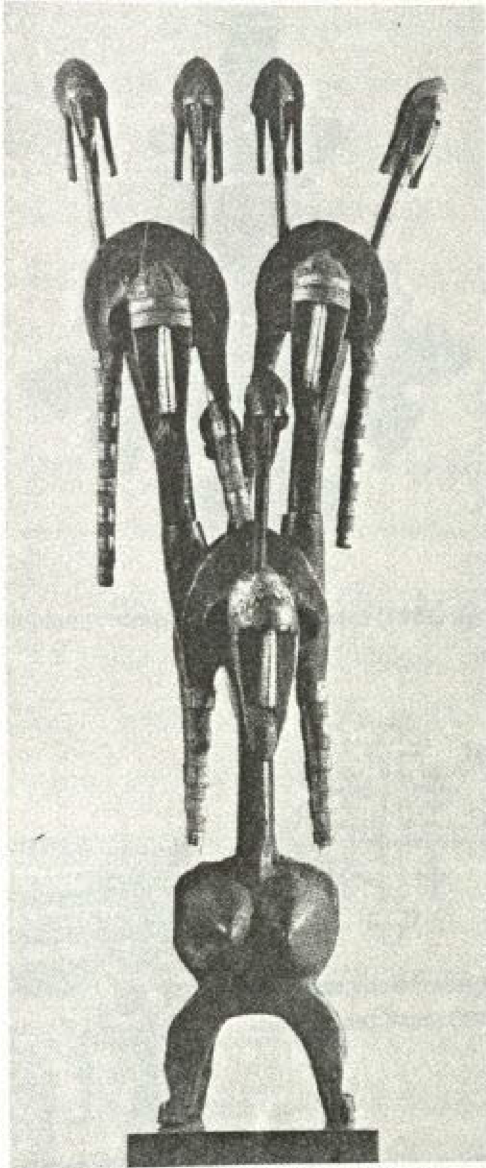
5.5) Fractals in African Art

That fractal architecture in Africa is conscious design, rather than unconscious statistical aggregation, is supported by the fractal designs in African art. Figures 12 and 13 show examples from several different locations. At the top left of figure 12 is a women's

Figure 5.12: Fractals in African Designs



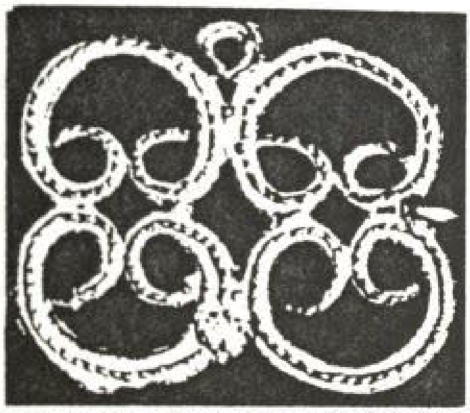
Chi Wara headdress. NY Museum of Primitive Art (1960) figure 54



Dance headdress. NY Museum of Primitive Art (1960) figure 43

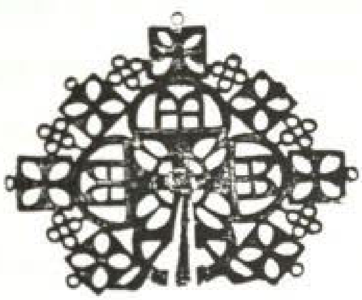
From Sagay (1983) pg 97.

Figure 5.13: Fractals in African Designs

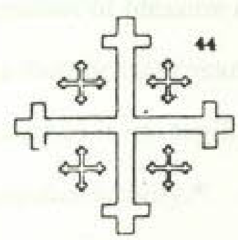


Akan goldweight. Cole and Ross (1977) fig 152.

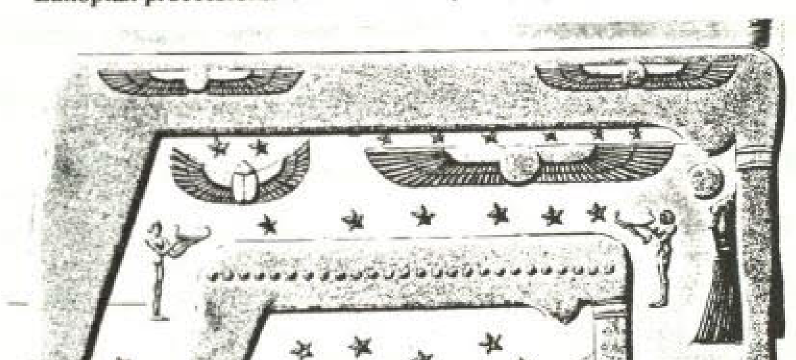
Ethiopian processional cross. Perczel (1981) fig 1.



Ethiopian processional cross. Perczel (1981) fig 2.



Egyptian grave inscription. Butcher and Petrie (1916).



Egyptian cosmology image. Description de l'Egypte (from Fourier's expedition), Paris 1820.

chi wara headdress from the Bambara. It is not so much the instantiation of a fractal as it is the algorithm for generating one. The imagery here represents the recursion of maternity. Since the baby will in turn become a mother with another baby on its back, there is an implication of infinite recursion. In chapter 1 we examined some instances where recursive aspects of sexuality became interwoven with the development of recursive mathematics in Europe; it would not be surprising if a similar relation existed in Africa.

Taylor (1990) describes sexuality in Rwanda as based on the notion of a "fractal person," in which the social universe is perceived "not in terms of monadic individuals but in terms of... structures of meaning whose patterns repeat themselves in slightly varying forms like the contours of a fractal topography..." (pg 1025). His analysis on expressions of this sociality in terms of the circulation of fluids is used to examine the failure of programs to encourage condom use. Clark (1989) analyzes Kikuyu sexuality in similar ways, contrasting European privitization of pleasure and authoritarian institutionalization of control with the Kikuyus' sexual regulation through public expressions of pleasure and "sociality of individual conscience." This description is parallel to a European/African difference in attitudes toward mathematics: typically African mathematics is not legitimized by institutional experts, but rather takes place in the realm of popular activity.*

Fractal patterns often occur in other types of African headdress where representation, rather than reproduction, is the subject of the display. The headdress at the top right of figure 12 portrays a person wearing headdresses of people wearing headdresses. Recursion in decorative patterns includes hairstyles (figure 12, bottom), weights, and jewlery (figure 13 top). Williams (1974) describes the *edan* brass sculptures in which

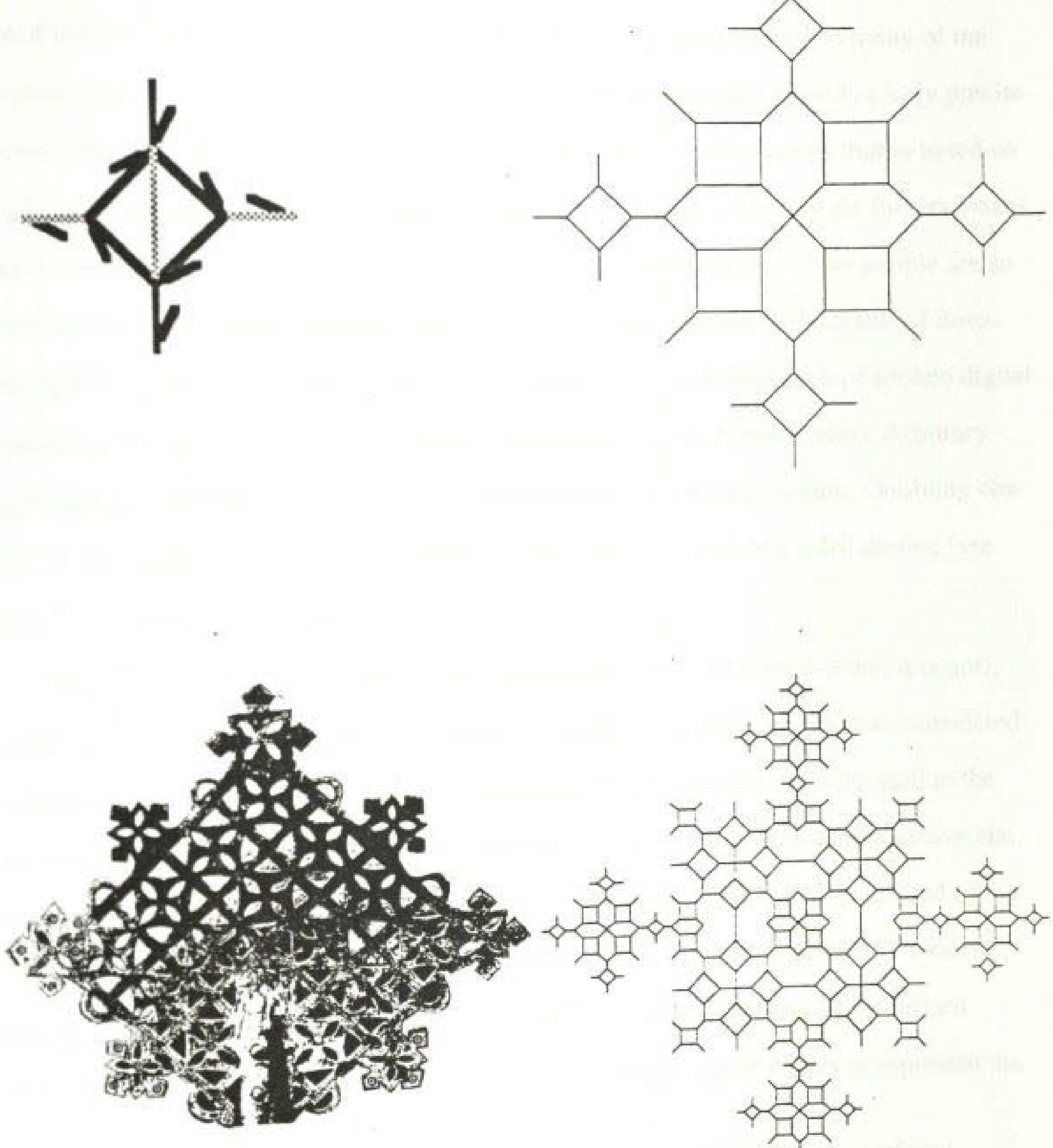
*This may also be related to distinctions between African and Indian uses of recursion. Murphy notes that the *Bhagavat Purana* uses the recursive imagery of the lotus flower to explain the world for those pursuing spirituality, but suggests a more euclidian model for those "trying to navigate their way through the material world." See Lawlor (1989, pg 73) on the mathematical differences between scaling designs in Egyptian and Indian architectures).

"one *edan* bears in its lap another, smaller, version of itself, and this bears another in its lap, etc." (pg 245), and notes that much African metal work, unlike European investment casting, uses the "spiral technique" in which we see "helical coils formed from smaller helical coils" (pg 184). It is important to distinguish these decorative fractals from those of Mandelbrot's "imitation of nature," whose self-similar scaling is common in several cultures (e.g. Chinese painting techniques). While African hairstyles may be picked up by Europeans searching for the 'Natural Look,' its local meanings are typically ones of artifice (e.g. braids of braids of braids representing layers of laborous styling and thus social investment).

In a survey of cruciform shapes on Egyptian graves, Butcher and Petrie (1916) found the self-similar pattern at the bottom right of figure 13 to be the most popular. Visualizations of the Egyptian recursive ontology can be seen elsewhere (figure 13 bottom), and will be discussed in the following section. The Ethiopian crosses, such as those at the top right and center left of figure 13, make particularly good fractals for computer graphics. Figure 14 shows a cruciform seed shape in recursive transformation to an Ethiopian cross simulation. This 'fractalization' of the European crucifix works both ways: the Knights Templar returned from North Africa with a cross made of crosses; the same can be seen in the Masonics' eleven-fold DeMolay cross. Are their other instances where possible African fractals made their way into Europe?

If by this question we mean the particular recursive cultural meanings of African fractals, the question is too ambiguous. There are such a wide variety of cultural meanings in these structures that there is little hope of any cohesive analysis or unitary history. But the *trivial* aspect of their commonality -- trivial in terms of its lack of inherent cultural meaning -- is indeed unitary and specific. The fact that they are all recursive structures has nothing to do with African contributions to arts or social history, but rather with African contributions to the mathematical sciences.

Figure 5.14: Fractal simulation for Ethopian cross design



Ethiopian processional cross. Perczel (1981)

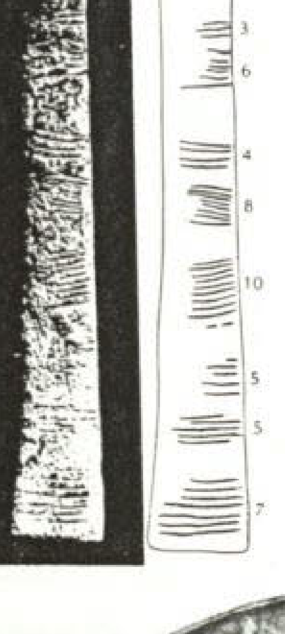
5.6) African Mathematics

The known history of mathematics in Africa starts with the Ishango bone (figure 15), which is dated around 7,000 BC. This is often interpreted as a doubling sequence: 3 to 6, 4 to 8, 10 = 5+5. The 7 is unexplained. Doubling is fundamental to many of the counting systems of Africa in modern times as well. For example, there is a very precise system of hand gestures (figure 15 top right) used in market transactions that is based on doubling. Europeans tend to use more analogical hand signals (i.e. any six fingers means six). It would be ironic if the colonial myth about African gestures -- "the people are so primitive that they cannot communicate in the dark" -- was actually the result of European ignorance of their market mathematics (that is, their supposed lack of spoken digital representation was actually the European's lack of gesticular digital codes). Arbitrary hand coding is currently prominent in African-American hip-hop culture. Doubling concepts in Africa also occur in notions around birth, as in the case of a spirit double (see figure 5.4d) or the significance of twins.

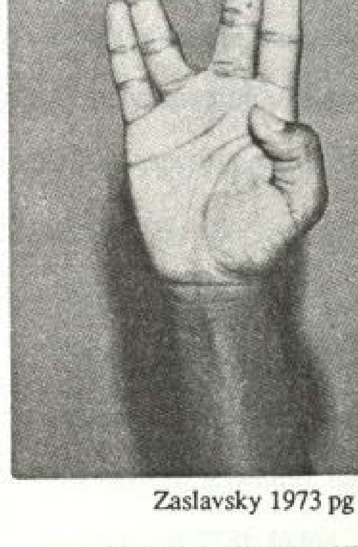
While 1+1 = 2 seems too easy to be mathematics (we will soon see that it is not), another African expression, infinity, seems too abstract. Indeed, infinity was considered a philosophic disease by most European mathematicians from Aristotle up until to the later 19th century.* Its symbolic representation in Africa, however, is less controversial, and is typically associated with health rather than sickness. Spiral shells are used in the fertility sculptures of the Baluba to represent the concept of infinite growth (Davidson 1978, pg 120). More common are snake spirals (see Gerdes (1985) pg 262, Garrard (1980) pg 294). Fraser (1974, pg 15) describes the Dogon use of spirals to represent the

*Aristotle ruled out infinity on the basis that it was selfannihilating (infinity + infinity = infinity), and therefore could only be a potential. Later mathematicians followed in this tradition, e.g. Gauss (born 1777): "I must protest most vehemently against [the] use of infinite as something consummated, as this is never permitted in mathematics" (Maor pg 54), a phrasing which recalls the connections to sexuality.

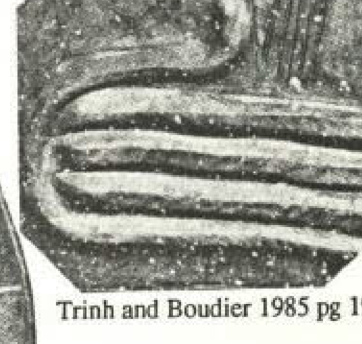
Figure 5.15: Mathematical symbols in Africa



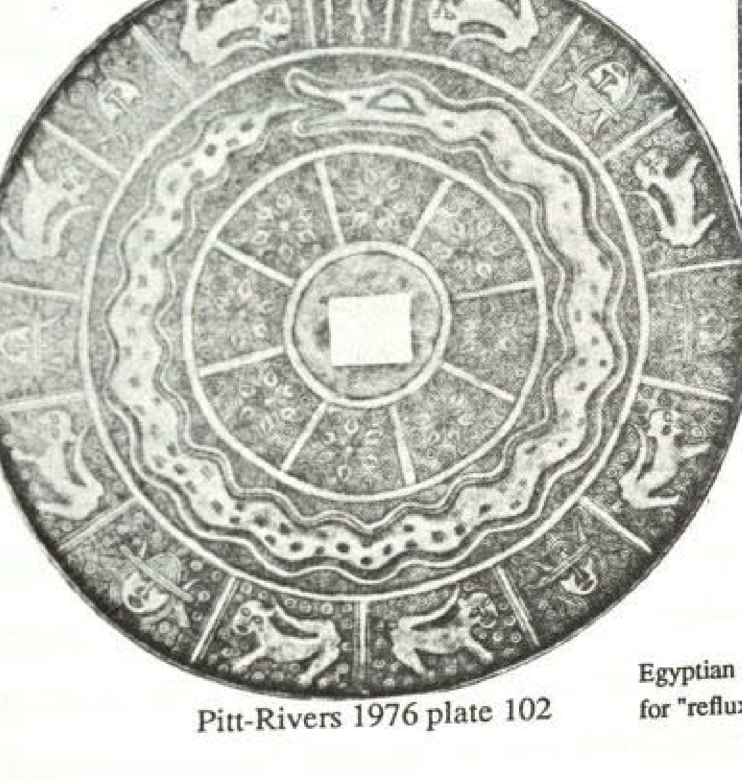
Zaslavsky (1973) Page 19



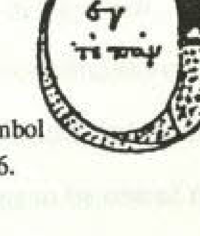
Zaslavsky 1973 pg 19



Trinh and Boudier 1985 pg 191



Pitt-Rivers 1976 plate 102



Egyptian alchemy symbol for "reflux." Alic 1986.

infinity of spiritual creation, and its manifestation in the cycle of agricultural fertility, and notes that the seventh deity of creation, which conveyed this knowledge to humanity, was in the form of a spiral snake. Nevadomsky (1988) provides evidence suggesting that the famous snake icons of Benin City represented the continual growth of the kingdom. The bottom right of figure 15 shows a relief from the interior wall of one of the circular settlements investigated by Trinh and Bourdier. This stylized representation of a snake coiling back on itself is said to symbolize eternal life or endless prosperity. Other versions of the snake motif are shown on figure 15 bottom left and center.

Egypt has been as an important interface between Europe and Africa, and mathematics served as key signifier for this border dispute. Bernal (1987) details the European history of the debate, and notes that it varies not only with differing racist strategies (e.g. explaining Egyptian achievements by asserting that they were white), but also with the changing status of mathematics as an academic discipline (pg 273). In his counter to the denials of Egyptian mathematics, Bernal emphasized the similarities between Egyptian and Greek mathematics, as well as the ancient Greeks' own testimony of their debt to the Egyptians. While I have no doubts about Bernal's thesis, he also mentions that there were some differences as well as similarities: "[In] the ancient view... the Egyptians had been the the possessors of a superior wisdom, which the Greeks had been unable to learn and preserve in its entirety." It may be that those those features of Egyptian mathematics which differed from that of the Greeks were the features shared by other African societies.

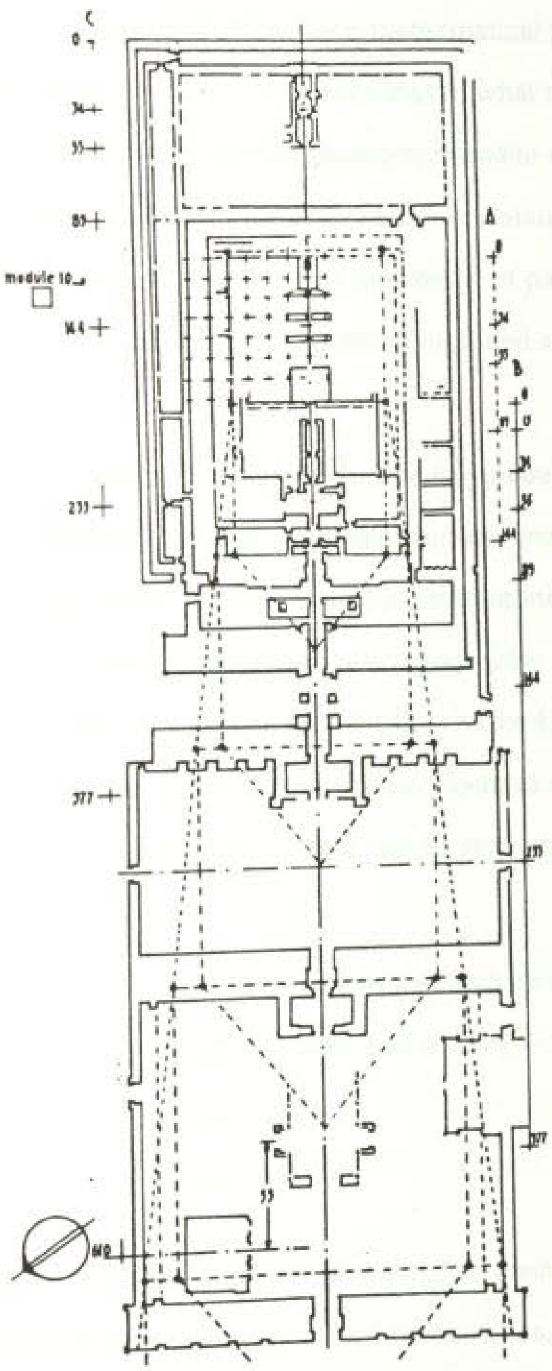
Egyptian measurement carvings clearly show numbers represented by stylized hand gestures (see Zaslavsky pg 50, fig 4-3). Doubling was very important in Egyptian mathematics, not only for simple counting systems, but also for more complicated operations. The Rhind Mathematical Papyrus shows that doubling was used as the foundation for a universal system of multiplication. This works because it happens to be one of the

features of the geometric progression given by the powers of 2; any integer can be expressed as a unique sum of terms from the sequence. Other progressions were also of importance. A geometric progression of 7 in the Rhind Papyrus has often been commented on because of its similarity to the European "St. Ives" rhyme, but it is probably more significant for its mystical implications (c.f. Lamy's comment on stansas 7, 70, and 700 of the Leiden Papyrus).

The most significant Egyptian sequence was the recursive arithmetic progression we know as the fibonacci sequence. Like the doubling series, it has a simple universality: any integer can be expressed as a unique sum of terms from the sequence. There is evidence suggesting that the Egyptians took advantage of this by using the fibonacci sequence for weights in their balance scales (Petruso 1985). They also used this sequence in their architectural design (Badawy 1965), as illustrated in figure 16. This is often referred to as "architecture by accretion," because once the pattern was started (1+1 = 2) future generations would continue to add on successive chambers. This can be viewed as a more formalized version of the self-organized architecture that produced the fractal patterns we see elsewhere in Africa.

In Greek design we often see the use of the golden section ratio, and several writers have attempted to show that this was important to the Egyptians as well. Bernal (pg 277) points out that the controversy seems to hinge more on a reluctance to believe in Egyptian cultural achievements than a dispute over the evidence. But even those who promote the Egyptian golden ratio claim note that it is not always consistent or highly accurate (e.g. Lamy 1981, pg 71). Boyer (1991) suggests that "[d]egree of accuracy in approximation is, after all, not a good measure of either mathematical or architectural achievement, and we should not overemphasize this aspect of Egyptian work" (pg 18). The significance of this caveat becomes more apparent when we consider the differences in derivation of the golden ratio in Greece and Egypt. The Egyptian value varies because it

Figure 5.16: Fibonacci sequence in Egyptian architecture



1+1 = 2
1+2 = 3
2+3 = 5
3+5 = 8
.
.
.
.
1,1,2,3,5,8,13,21,34,55,89,144,233,377,610

Badawy (1965) Page 119, "Karnak."

is produced in their designs through the ratio between successive numbers of the fibonacci sequence, which *converges* to the golden ratio. There is no evidence that the Greek mathematicians knew of the fibonacci sequence.* Moreover, mathematical progressions of the golden ratio, such as the fibonacci sequence, always lead to what the Greeks termed "irrational" numbers, line segments which were incommensurable with whole number ratios. Boyer (pp. 72-76) notes that this discovery was of devastating significance for the Pythagorean school. Together with the related discovery of paradoxes in infinity, a "Platonic reform" became necessary in which abstraction and stasis were emphasized.

Thus the golden ratio had cultural significance for both Greeks and Egyptians, but in opposite ways. For the Greeks the golden ratio represented an object from the unchanging realm of eternal forms; for the Egyptians it was the changing result of an infinite series through which past and future fused together. This notion of time was also emphasized in their quantitative search for cyclic patterns in the Nile floods (see Hurst in the following section), and is suggested in their artistic depiction of movement as an undulatory time series (Badaway 1959). Such cyclic views of time can be seen elsewhere in Africa.

The following section will describe some of the possible routes by which these features of African mathematics -- cyclic time, recursive sequence, and infinity -- may have made their way into the history of fractal geometry.

5.6) The African Geometry of Fractals

Although Aristotle's condemnation of infinity banned it from European mathematics for two millenia, there were occasional attempts to re-established its existence, and

*There was use of the fibonacci sequence in Minoan design, but Preziosi (1968) notes that this may have been brought from Egypt by the Minoan architectural workers employed at Kahun.

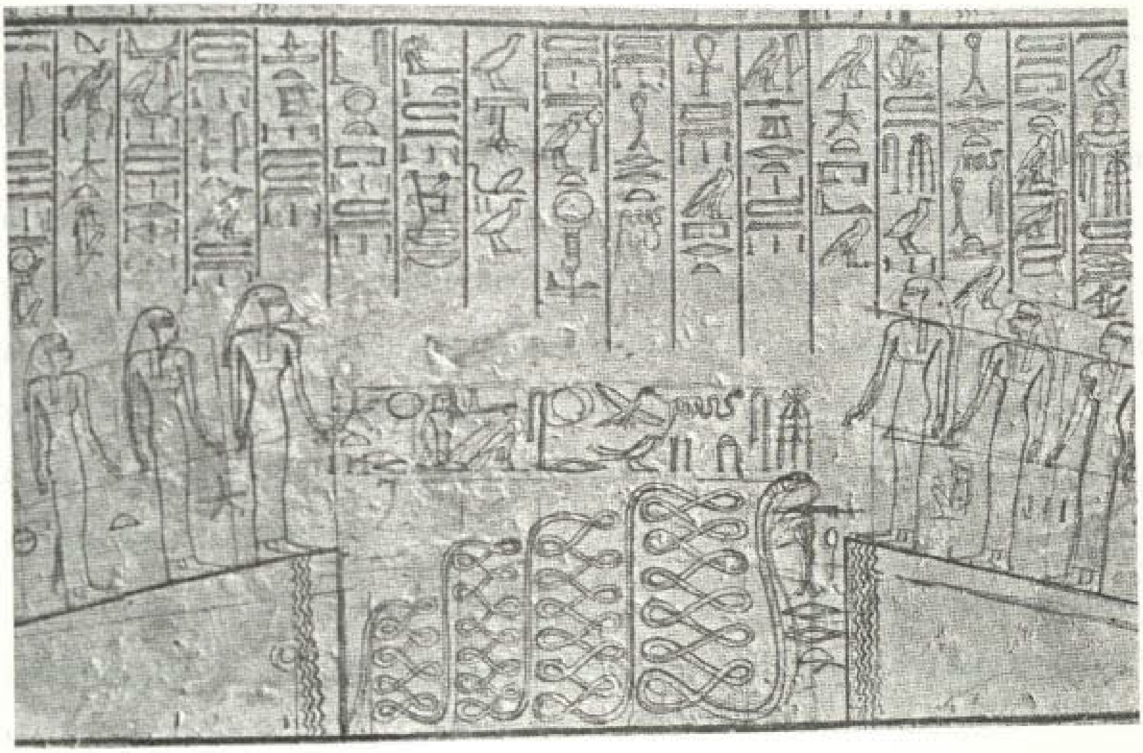
the European infinity symbol was introduced by John Wallis in 1656. It is generally assumed that he took it from the Roman symbol for 100 million, which is the infinity symbol with a square around it, but there is no direct evidence for this, and he could have taken it directly from the Egyptian snake symbol (figure 17), or the Romans could have adopted the Egyptian symbol themselves (since 100 million was their largest number, it could have been seen as 'infinity in a box').

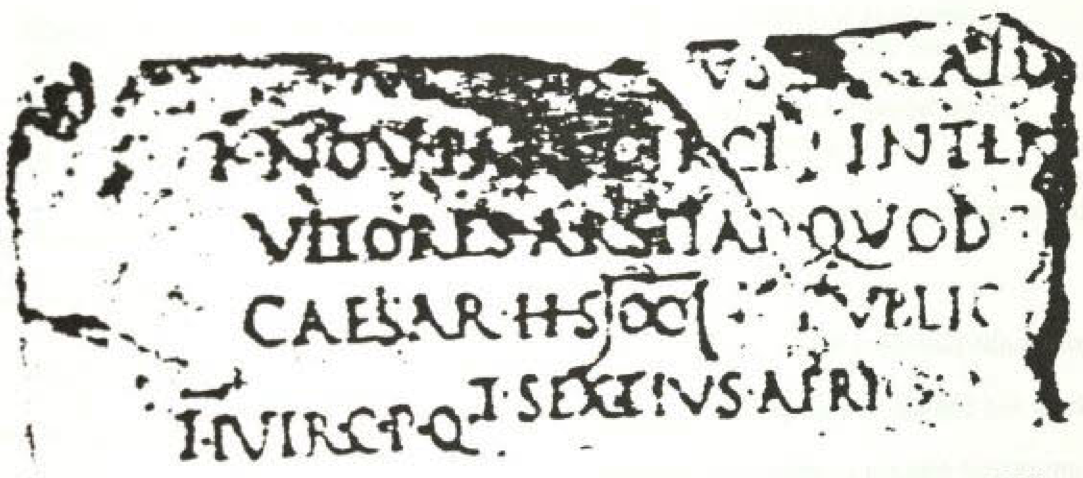
In 1190 AD Leonardo Fibonacci was sent from Italy to North Africa to learn the shipping business from his father. He was more interested in the accounting, and after traveling through Egypt, Syria, and other areas he wrote a famous mathematics text which introduced Hindu-Arabic notation to Europe. The fibonacci sequence was just one minor illustration of geometric progression. Its real mathematical significance was not appreciated until the work of Lucas and Bernoulli centuries later. Bernoulli's extension of recursive sequences was put into a computational framework by Ada Lovelace, as noted in chapter 1. The fibonacci sequence was the first successful mathematical model of natural growth structures -- its sequence appears in pinecones, shells, etc. -- and was used as a starting point by Alan Turing when he began computational modeling of biological morphogenesis.

The first modern recognition of the mathematics embedded in Egyptian material culture came out of Napoleon's expedition to Egypt in 1798. The violent imperialism of this effort was glossed over by the excuse of a scientific expedition, and as the head mathematician of this group Napoleon chose Joseph Fourier. Teams of architects, painters, and other professionals analyzed the Egyptian ruins in exacting detail.

Fourier himself was previously uninterested in dynamic or harmonic mathematics; he had earned his reputation by producing proofs for the theory of equations proposed by Descartes, which was solely in a static framework. During the Egyptian expedition he dropped his Cartesian studies, and started modeling oscillations of heat distribution. His

Figure 5.17: Possible African origins of the infinity symbol





Top - Hornung (1971).

Center - Menniger (1977).

Bottom - Maor (1987).

solution, which created the fourier transform Peter Broadwell and I used to analyze African architecture, has several parallels to Egyptian mathematics. First, the transformation of perspective: Fourier's system viewed change in the frequency domain, and the Egyptians were similarly interested in a cyclic view of changes. Second, a universality property: recall that the Egyptians found that you can represent any arbitrary integer by summing selected terms of certain arithmetic series. Similarly, the Fourier transform says that you can represent any arbitrary function by summing selected terms of certain trigonometric series. Third, there was the convergence of the infinite series to a finite value, and Fourier's graphical representation of this (figure 18) is similar to the architectural diagrams he examined for Egyptian buildings, which also show convergence to a finite value (the golden ratio).

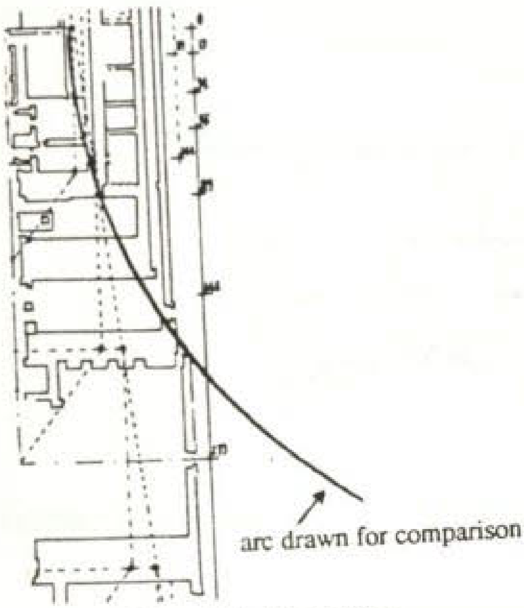
Least anyone accuse me of injecting an interpretive process where pure mathematics and internal theorem-proving would suffice, let us read from the standard internalist history, Langer's "Fourier Series - the genesis of a theory."

> Elegant though the conclusion unquestionably is, the verdict of any critical appraisal must ... be profoundly disapointing. As to the result, that was not new. It had been reached by Euler [in the year 1777]. Nor could any advantage be claimed by method. Fourier's claim to renown must be based upon other grounds, and these are, namely, those of interpretation (pg 41).

Langer goes on to mention the frequency domain and universality from convergence as these interpretative innovations.

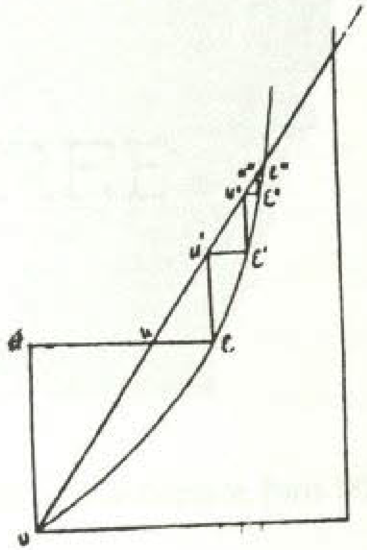
Fourier's work is not usually considered a part of fractal history; Benoit Mandelbrot cites Georg Cantor and H.E. Hurst as his true forebears. Georg Cantor started his work in a study of the Fourier series, so there is a connection. But there is a more intriguing possibility of Cantor's African influence. Figure 19 shows Cantor's (and Europe's) first official fractal, the midpoint displacement of the unit interval, zero to one. Next to this is an illustration of one of the capitals of an Egyptian column, which shows a strikingly

Figure 5.18: Possible Egyptian influences in Fourier



Fibonacci Series of significant points

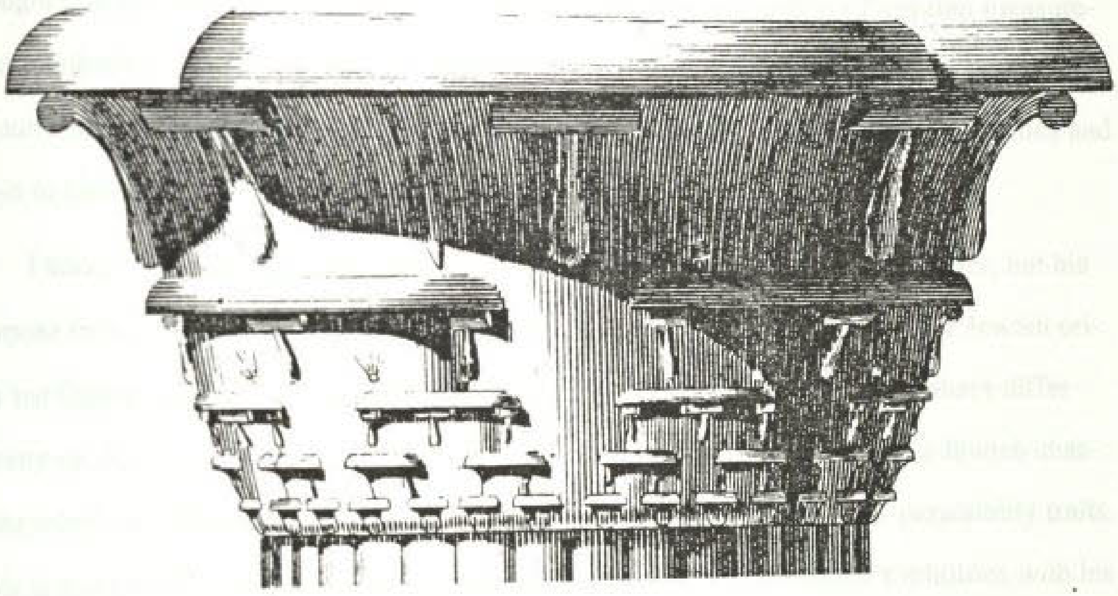
Badawy (1965) Page 119, "Karnak."



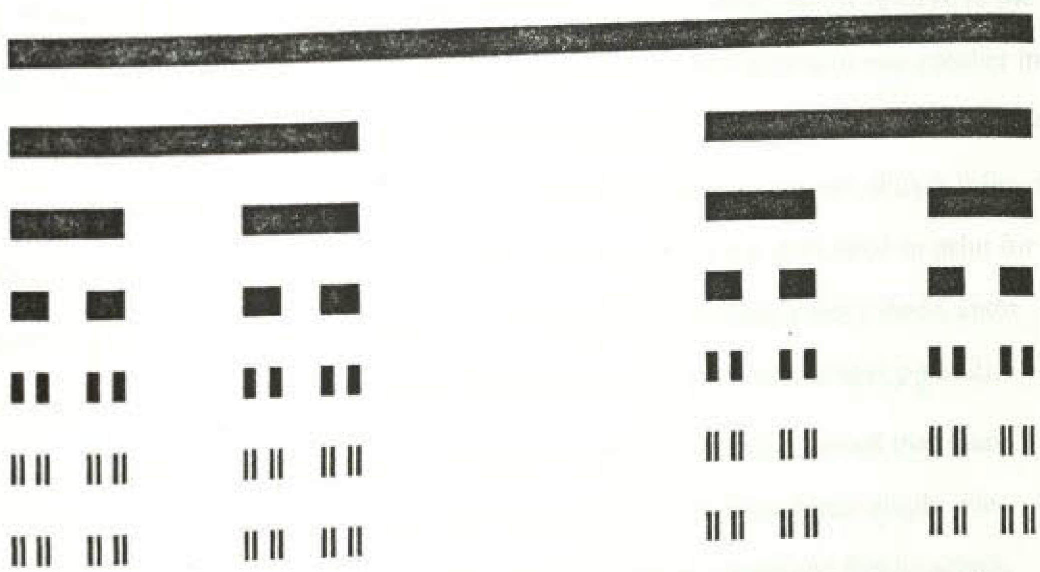
Théorie de la propagation de la chaleur. Art. 99

Grattan-Guinness 1972 pg 297

Figure 5.19: Cantor set in Egyptian Capitals



Egyptian capital representing the lotus. From *Description de l'Egypte,* Paris 1820.



The Cantor set. From Mandelbrot (1982).

similar midpoint displacement pattern. The structure is a formalization of the water lily, which the Egyptians used to symbolize the biological recursion of reproduction. At first I thought this was just a cute coincidence, but when I was researching Egyptian measurement methods I came across a citation to Cantor, 1863. This turns out not to be Georg Cantor, but his relative Moritz Cantor, who was an authority on ancient mathematics and lived in Germany at the same time as Georg.

I know that Georg knew about Moritz because he mentions him in a letter, but his purpose in writing was to deny that they were related. Both Cantors were of Jewish origin but Georg's side had converted to christianity. Georg Cantor's biographers differ greatly on the significance of this point. E.T. Bell felt that Georg Cantor's Jewish character ruled his life, and makes several remakes about the inheritance of personality traits. This is particularly disturbing in the context of his remarks on Cantor's relations with his arch rival, the Jewish mathematician Leopold Kroneker: "There is no more vicious academic hatred than that of one Jew for another when they disagree on purely scientific matters. When two intellectual Jews fall out they disagree all over, throw reserve to the dogs, and do everything in their power to cut one anothers' throat or stab one another in the back" (1939, pp 562-563). Another Cantor biographer, J.W. Dauben, says that since Cantor's mother was Roman-Catholic "she was by definition non-Jewish, thus it follows that Georg Cantor was not Jewish, contrary to the view which has prevailed in print for many years." Nazi scholars solved their own worries by spreading a story that Cantor was found abandoned on a ship bound for St. Petersberg (Grattan-Guinness pg 352).

Actually Cantor's Jewish identity was quite complex. Having proved that there were higher infinities, he proceeded to rank them using the Hebrew letter aleph. He referred to his grandmother as "the Isrealite," and eventually joined the Rosicrucians, who believed that ancient Egypt held the key to an original unspoiled religion. Following his proof of infinities greater than infinity he had a brief stay in a mental hospital,

where he became convinced that God had put him on earth to produce higher mathematics, and wrote a religious tract claiming that the real father of Jesus Christ was Joseph of Arimathea.

While I sometimes read the assertions of Georg Cantor's christianity as math history writ small, the denial of a history of mathematics to the non-European, I think the most useful aspect of his ethnic identity is symbolized by his non-euclidian geometry. While his biographers argue Jew or not-Jew, on or off, zero or one, Cantor himself proved that the continuum from zero to one cannot be delimited by any subdivision process, no matter how long its arguments.

In addition to Cantor's abstract mathematics, Mandelbrot credits the empirical work of H.E. Hurst in inspiring his development of fractal geometry. Hurst lived in Egypt for 62 years, and was able to demonstrate long-term scaling in Nile flood records because of the accurate "nilometer" readings going back 15 centuries. Hurst is particularly interesting because his initial studies (Hurst 1931) made heavy use of a series of aerial photos taken from the source of the Nile to its mouth. These photos often show settlements, and there is an obvious tendency toward more Euclidian patterns as he moves toward the more colonial settlements in the North. In other words, he was looking at Fractal/Euclidian contrasts in African architecture at the time he did his mathematical work.

There are several figures in computer science who may also have derived some of the recursive aspects of their work from Africa: N. Negroponte, whose work at MIT in self-organized machine architectures was inspired by a text on "primitive architecture;" Seymore Papert, a white American (originally from South Africa) whose work on recursive computing followed his UN work in Senegal; and Earl Jones, an African-American computer engineer who did seminal work in distributed data networks (Sertima 1984, pg 283). Also relevant to this history is E.E. Just, who used music as both a conceptual

model for decentralized biological morphogenesis, and as a cultural basis for understanding his African heritage (Manning pg 203, 261). Just's work was taken up by Ross G. Henderson, who was an important influence in the General Systems Theory community (Haraway 1976). Most recent is the acclaimed parallel computing work by Philip Emeagwali, a Nigerian-born graduate student at the University of Michigan. But it was Benoit Mandelbrot who fused recursive computer graphics with recursive set theory, thus sealing his claim as the "Father of Fractal Geometry."

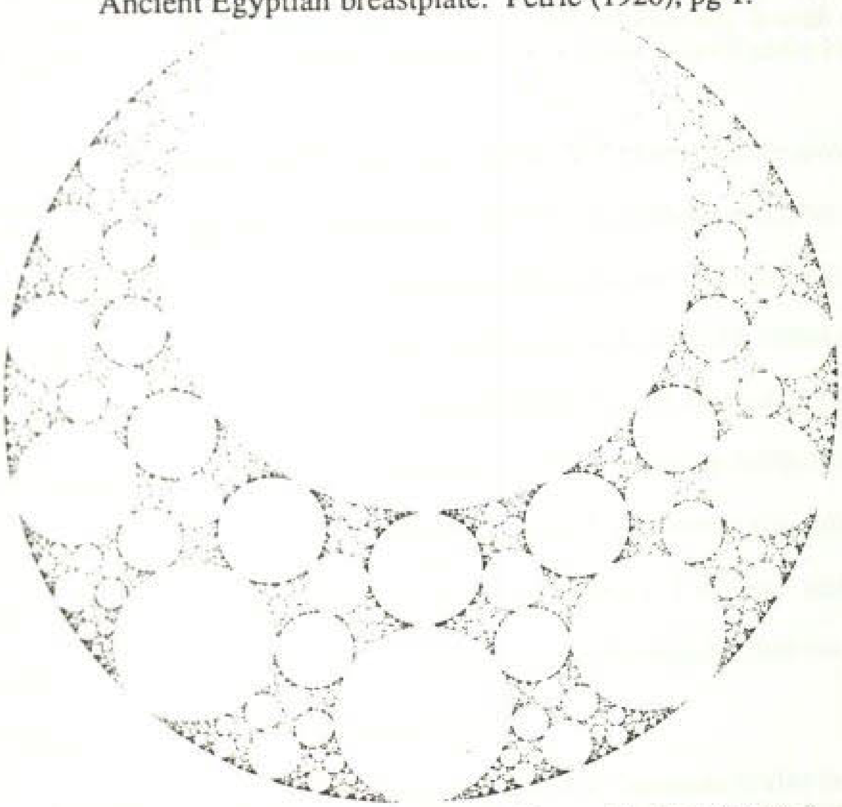
The bottom of figure 20 shows a fractal Mandelbrot titled the "Pharaoh's Breastplate;" a real Egyptian breastplate is shown at the top. There are references to Semitic culture throughout Mandelbrot's text. Fractal images incorporate both the star of David and pyramids, and his discussion of Hurst's scaling data starts with his neologisms, "Joseph effect" (seven years of plenty followed by seven years of famine) and "Noah effect" (long term flooding). Memory and identity are particularly important for Mandelbrot. As a young Jew in France during WWII he had to disguise his ethnic identity, and he mentions the lessons of this experience in a recent interview (Barcellos 1985):

> Poverty and the wish to keep away from big cities to maximize the chances of survival made me skip most of what you might call college.... But I soon came to view the unpredictability of life as contributing layers or strata of experience that add up to a valuable combination (pg 208).

Mandelbrot sometimes intimates a connection between authoritarian attitudes and the suppression of Cantor's non-euclidian geometry. He constantly brings up the accusation of chimera, gleefully noting that just as the chimera is an in-between beast, fractals are in-between whole dimensions. At the end of his text, he adds "Incidentally, in the ancient Hebrew cultural tradition chimeras were neither ignored nor rejected, as demonstrated from a surprising angle in Soler 1973." Soler 1973 is titled "the dietary prohibitions of the ancient Hebrews." Apparently chimeras are kosher.

Figure 5.20: Egyptian breastplate and Mandlebrot's simulacrum

Ancient Egyptian breastplate. Petrie (1920), pg 1.



Mandelbrot (1982) Plate 199, "The Pharaoh's Breastplate."

Conclusion: The Fractal Geometry of the Arabesque

In writing this chapter I was much inspired by Martin Bernal's *Black Athena,* although I ended up emphasizing the differences between Greek and Egyptian rather than using his synthetic approach. Bernal's brief discussion of the relation between his historical work and his Jewish "roots" reminded me of my own reflections, and of that dangerous pivot of the Afro-semitic, Israel. The following is my attempt to use chaos as a way to bring some order to that precarious hinge.

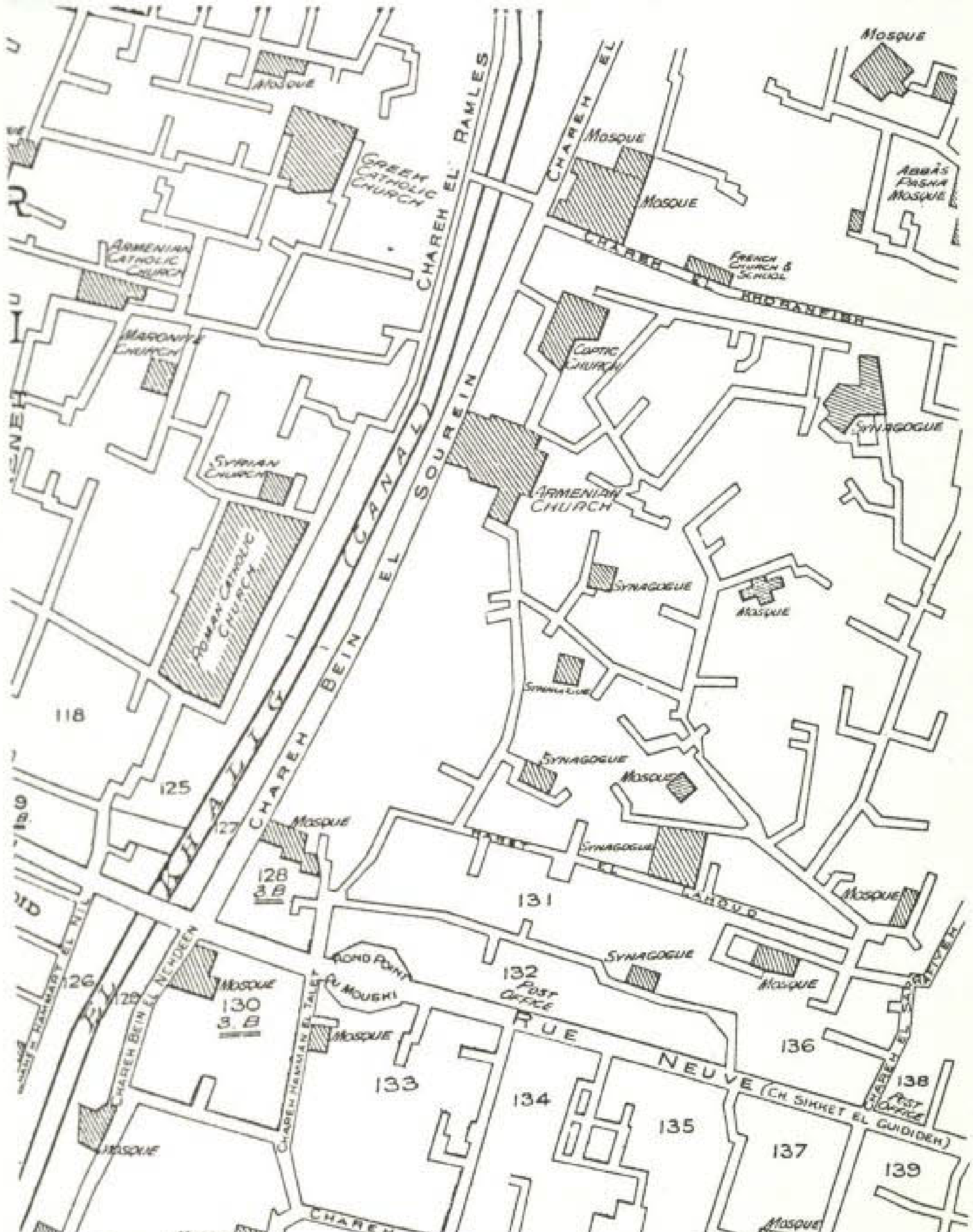
Hannon Heaver recently gave a reading of the novel *Arabesques* by Anton Shammas, in which cyclic time and multiple identities articulate a political flexibility crucial to the survival of cultural diversity.

> As an "Israeli Arab," Shammas is a member of a minority group - but as a Christian, he falls outside the Islamic mainstream of the minority.... On the other hand, he writes in Hebrew, the language of the dominantly Jewish culture, which is itself a minority within the pre-dominantly Arab Middle East" (p 49).

Shammas uses the image of a Russian *matrishoka* doll to explain his own identity. Such recursive nesting is emphasized throughout the temporal flow, narrative structure, and conceptual dynamics of the novel. Heaver suggests that the "nonmimetic geometrical abstractions of the arabesque" are a spatial model for Shammas. He notes that in part these cyclic re-entries act to negate each other; undermining, for example, the fruitless argument of "I was here first." But negation is not the only meaning behind the arabesque, as Heaver points out in a passage which ties Islamic social structure to analog representation, recursion, and the scaling properties of fractals. I will end this chapter with this passage and one last illustration, a flowering of religious institutions at the ends of the fractal branches of Cairo seen earlier (figure 21).

> The arabesque does not serve only a negative, critical function; it also bears a positive, utopian message. It acts as an analogue, in the area of visual arts, to the position of Islamic "contractualism" in the social sphere.... In contrast to western corporativism, with its preference for hierarchical structures in which

Figure 5.21: Map of streets of Cairo, 1898



a limited number of conclusions are drawn from a limited number of premises (on the model of [euclidian] geometry), the cyclical rhythms of the arabesque could well be said to characterize an "indefinitely expandable" structure. The arabesque provides a framework within which it becomes possible to reduce the apparently "chaotic variety of life's reality" to manageable proportions, yet without "arbitrarily setting bounds to it" (p 61).

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Epilog

In parallel to the Afrosemitic diasporic circulation I have attempted to elucidate, the last chapter moved from Semitic cybernetics to African chaos, and should now move back to Semitic chaos (chapter 1) and from there to African cybernetics (chapter 4). In other words, the proper ending to this text is its beginning. This epilog is thus left as a brief pause outside the loop; more of an accessory than a summary. I want to use this supplement to fill in one last gap: assuming that my work has some place, however odd, in scientific studies of society, we have yet to see where it fits in with social studies of science. In particular, I want to caution my readers against thinking that this text is promoting some sort of recursion panacea. In the context of cultural and political resistance, there is much more to social studies of science than counting up lots of loops.

Throughout this text, there have been two theoretical frameworks which bear on social studies of science. The most apparent is my two-dimensional analysis of holism (fig 2.1a). I have tried to show that the cultural claim for an ethics of holism has developed in a mutual historical construction with the scientific claim for a cybernetics of holism. Along one axis we have the parallels between recursion in humanist theories of liberation, and recursion in technical theories of computation. Along the other we have the organicists' romantic depictions of more concrete, more natural communication, and the cyberneticists' pedantic systems for less discrete, more analogical representation. This analysis has two important attributes in terms of social studies of science. First, it is yet another example of side-stepping the old externalist/internalist debate. Rather than claiming that external society transforms science, or that science operates autonomously through its own internal rules, my portrait of mutual construction attempts to demonstrate that the very distinction between these two spheres is not a tenable assumption. Second, the ethical holism position is itself a popular theme in certain social studies of science. The implication for such studies is quite direct -- my historical constructivist description is specifically opposed to the claim that holism is *inherently* more ethical -- and it is this

latter implication that I will take up further in this epilog.

The second framework for science studies in this text is that of essentialism. In chapter 4, we saw not only the ways in which more holistic cybernetics (that is, more analogical representation and more recursive information) could be expressed in terms of phase space objects, but also how the apparently global aspect of phase space could be dismantled ("deconstructive dynamics") into a profusion of different (equally objective, but not equally useful) dimensions. In terms of cultural analyses, we have looked at not only the ways in which more holistic cultural phenomena could be expressed in terms of representation through physical dynamics and more decentralized organization, but also how the apparently global nature of such identities or processes could be dismantled into many different -- sometimes contradictory -- facets. For example, a claim that "women are ethically superior because they are more holistic" would not only be problematic because holism is not inherently more ethical, but also because the category "women" does not reduce to this single essential position on the map.

How do these two frameworks, ethical holism and essentialism, operate in the field of social studies of science? I want to briefly review recent work by Sandra Harding centered on feminist science studies, and (even more briefly) contrast this research to the reflexivist approach of Steve Woolgar. In doing so, I hope to show how the two frameworks can operate independently, in what ways they become linked, and how such structures are related to the context of cultural and political resistance, struggles, and oppositional practices in which I would situate my own work.

Harding begins with a trinary typology of feminist epistemology. Her "feminist empiricism" category is defined as distinguishing between biased science, in which sexism can cause objectively less-true results, and unbiased science, in which proper methodological inquiry eliminates such cultural contamination. The "feminist standpoint" category argues that a subjugated position allows for a more complete understanding of

the world, and thus grounds a more accurate perspective for scientific inquiry. Harding notes that while this standpoint move allows a strong critique of the methodological norms of science-as-usual, it also tends toward a more unitary or essentialized view of women. In contrast to this universalizing tendency, her third category of "feminist post-modernism" is defined in terms of resistance to any universalizing narrative, including both science and an essentialized identity for women.

Harding attempts to use the standpoint theory as middle ground, and promotes a synthesis between all three positions, but in this generosity the universalizing tendencies come to dominate the discussions. While the standpoint epistemology is not inherently essentialist, in this 1987 text it is based on a model of objectivity which requires universality, and thus becomes biased toward essentialism. Not surprisingly, this essential identity of women in relation to scientific practice turns out to be a holistic one, so that the end result of Harding's standpoint theory is equivalent to my ethical holism category, but the framework in which its claims are generated turns out to have much more complex implications.

On the holistic, essentialist side, Harding often slips into a deterministic view of analog/digital differences. Quantitative measure, law-governed behavior, formal system representation and other digital associations are attributed to "a distinctly masculine tendency" (pp. 105, 229). She is somewhat more suspicious of finding liberation inherent in the analogical realm, questioning (though never really refuting) the way in which analog aspects of craft labor (Rose 1984), ecological concerns (Merchant 1980), and "non-Western" science (Needham 1976) are promoted as the holistic solution to reductionistic oppression. Particularly disturbing is her claim for a "curious coincidence" between African and feminine world views. Her use of recursion, primarily in terms of calling for "reciprocal, interactive relations," also makes ethical holist assumptions. This is most apparent in her use of Smith's (1979) sociology of housework, where "the authority of

the inquirer" is put "on the same epistemological plane as the subjects of the inquiry" -- precisely the kind of self-determination Foucaultian critiques see as possible self-exploitation (and as I have tried to outline for postmodern industrial management in chapter 3).

On the non-essentialist side, Harding notes that science makes use of both masculine and feminine characteristics, and that the androgyny sometimes touted as a feminist ideal often exists in terms of men appropriating "female characteristics" for their own purposes. She adopts the postmodern device of "fragmented identities," in which there is no single true female essence, but rather a community of conflicting and complementary identities. Yet she seems reluctant to release control of this assemblage: "I argue for the primacy of fragmented identities but only for those healthy ones constructed on a solid and nondefensive core identity..." (pg 247).

Finally, Harding also manages to utilize the biased science critiques of Longino and Doell (1983).* Although these are again incorporated into an ethical holism narrative (pg 105), her path along this route specifies how the feminist standpoint, this subjugated perspective, can enter into an analysis of the particular biological science practice detailed by Longino and Doell. In other words, the framework of women's standpoint seems to repeatedly tempt Harding into a monolithic, essentialist account; but the methodology in which it operates is by no means so restrictive.

This open-ended aspect of the feminist standpoint epistemology is supported by Harding's more recent work (1991), in which she attempts a much stronger alliance with postmodernist anti-essentialism. Again, some of her analysis still shows occasional ties to the ethical holism position -- in particular, her call for "reinventing ourselves as other"

*Actually Longino and Doell were quite wary of the biased science paradigm, and specifically rejected that conclusion (pp 207-208), but Harding suggests that their work was fundamentally adherent to this framework despite their efforts to the contrary (a critique supported by Longino's later endorsement of a "minimalist form of realism" (1990, pg. 222)).

recalls the mimetic trope of organic romanticists.** But even here there is some ambiguity; the new account of African epistemology is no longer the intuitive naturalism of holistic consciousness, but rather Sertima's (1986) collection of studies on indigenous technologies in African societies. On the whole, her feminist standpoint epistemology has now been amended to a more plural "standpoints." This wide incorporation -- from biased science to postmodernist anti-essentialism -- shows how the politicizing actions of feminist science studies have provided a dynamic which allows an alliance despite the disparity of theoretical positions.

Although these arguments from subjugated positions tend to highlight the cultural construction of science at the expense of allowing essentialist realism, some of the other orientations in social studies of science -- here I will concentrate on that of Steve Woolgar, who typically presents himself as a neutral observer -- tend to highlight the anti-realism view of science at the expense of a flaccid cultural account. They give us a smorgasbord of mechanisms to explain how science works by social rather than realist explanations -- by networks of allies, inscription devices, inversion of discovery, etc. -- but little notion of what could be governing the dynamics of this social sphere. In such accounts science might as well be driven by a singular objective reality, since the account of social construction is a form without content.

The irony of such "neutral" science studies is that their neutrality is modeled on scientific claims to value-free observation. This recursive contradiction is not avoided by these investigators, but rather upheld as evidence of their cutting-edge philosophical abstraction; the "reflexive" move. For example, in response to Winner's (1986) famous example of bridges on Long Island, which were designed to prevent public buses (and

**A move discussed in my analysis of hippy subculture's interpretation of analog representation as non-representational or Real (chapter 2). See Campbell (1992) on the men's movement as a contemporary example.

thus low income groups, such as Black citizens) from park access, Woolgar (1991) objects that there is no basis for choosing this politicized reading of the technological "text" over the usual neutral readings. "Pushed along one step further, the reflexive version of technology as text suggests that all versions (descriptions, accounts) of technology be granted no greater authority than any other outcome of textual production and interpretation" (pg 41). In Woolgar's reflexive framework, Winner's own text is also a technology, so it too must be seen as mere social construction rather than revealing True Reality. Since Woolgar's refusal of absolute truth status would include Woolgar's own texts, we are assured that it is theoretically possible to oppose racist engineering and still be faithful to Woolgar, but that opposition was hardly a major concern.

How can we maintain both the philosophic integrity that the reflexivists call for, and the cultural depth that politicized readings provide? I want to suggest two methods for approaching this problem. The first, that of my own work as well as of several other researchers -- E. F. Keller's slime mold studies for example -- is *cheating*. In the game that divides science practitioners from science studiers, we can always cheat by crossing the line. The fact that Keller and I differ in our attitudes toward holism is irrelevant. What matters is that by actually doing science as part of our work, we prove our versions of deeply cultural constructions of science through objective, empirical methods. Since cultural construction undermines truth claims for these objective, empirical methods, the cultural construction is also brought into question. But if cultural construction is not true, then there is nothing to prevent our complete confidence in the objective, empirical methods. It is a paradox based on self-contradiction.

The second method we might look towards are those players who go by the rules, but still invite paradox in their theoretical stance. Haraway (1988) for example, embraces paradox in her feminist reconceptualization of objectivity as "situated knowledges." She notes, for example, that scientific visualization techniques do not

necessarily imply obedience to a singular vision, but rather open a profusion of viewpoints -- all objective, but from radically different perspectives and along orthogonal spectra.* "There is no single feminist standpoint because our maps require too many dimensions...." As Haraway notes, the insistence on knowledge that is both objective and multiple can be seen in many other traditions -- in the Native American trickster mythologies for example.

It may be that paradox is just a passing phase; a side-effect of poorly crafted theories of science, which will be seen as useless distractions to improved social studies of science in the future. Yet I cannot help wondering at the ways in which self-reference and uncertainty seem to force themselves upon science. When students in the May '68 protests of Paris wrote "To forbid is forbidden," they must have realized that once we begin to use recursive critiques, there is no higher level that remains immune; similarly there is no point in practicing the "meta-upmanship" (Davis 1990) in which that some postmodernists currently revel. It's not the number of loops we have, but what we are looping that counts.

*See chapter 4 of this text for a more detailed mathematical interpretation of Haraway's proposal.

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